

Uranium in Minnesota

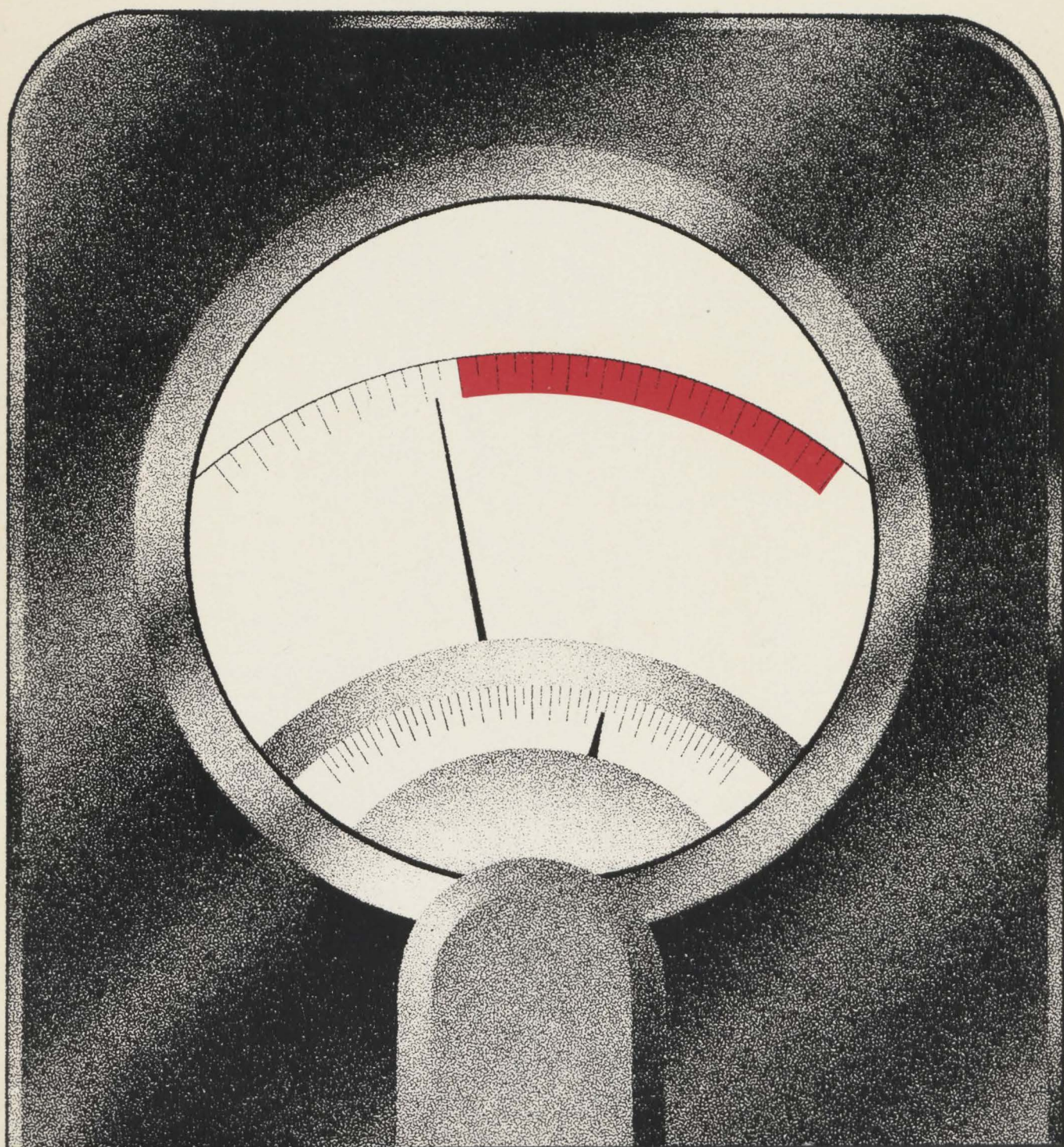
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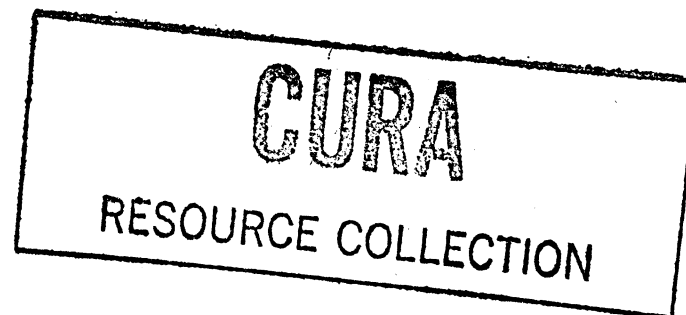
an introduction to exploration
mining and milling

CURA

By Dean Abrahamson and Edward Zaborni

RESOURCE COLLECTION





Uranium in Minnesota

an introduction to exploration
mining and milling

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It proved difficult to produce a final text that completely satisfied each of the reviewers, who have diverse backgrounds and interests. Thus, while acknowledging their help, the authors assume final responsibility for the contents.

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INTRODUCTION TO THE SECOND EDITION

Uranium, first discovered in 1789, is not a rare metal. Concentrations rich enough to warrant mining, however, are relatively scarce, and the principal locations in the United States have been in the West and Southwest. In 1949, the first exploration for uranium took place in Minnesota, and in the past few years, exploration has intensified, particularly in Pine and Carlton counties in the northern part of the state. Recently, a substantial quantity of private land in Minnesota has been leased for exploration and mining, and leases for state-owned land are being considered. Thus Minnesotans, who have been evaluating the potential advantages and disadvantages of copper-nickel mining, may soon have to consider uranium mining and milling as well.

In 1978, the All-University Council on Environmental Quality began receiving requests for information about the possible environmental impact of uranium exploration, mining, and milling. As a result, the council decided to prepare this summary of some of the issues associated with uranium mining.

The intent of this booklet is not to describe completely the uranium mining industry, or even to fully discuss the environmental quality issues associated with uranium mining and processing. We hope only to provide, in non-specialist language, an introduction to uranium mining and milling, stressing those environmental hazards that seem, on the basis of experience elsewhere, to present the most concern. Minnesota has considerable experience with iron and taconite mining and milling, and is still evaluating the environmental impact of copper-nickel mining. Except for the additional hazards resulting from radioactivity, the impact of uranium mining is similar to that of other mining activities.

This booklet emphasizes the radiological hazards associated with uranium mining. These hazards include the possibility of ground and surface water contamination, airborne emissions of radioactive materials, occupational exposures to radiation in mining and milling, and, perhaps most troublesome of all, the long-term effects of radioactive wastes resulting from uranium milling. These are major environmental and occupational issues with which Minnesota's public agencies have relatively little experience.

Throughout the booklet we have attempted to avoid technical jargon and specialized language. The appendices describe in more detail the radioactive materials of concern in uranium mining, the biological effects of exposure to radiation, and the relationship between uranium mining and the nuclear fuel cycle. A bibliography includes some of the sources used in preparing this booklet, along with other references that may be useful to those seeking more detailed information.

Any discussion of uranium mining and milling policies inevitably involves the broader questions associated with atomic power, since virtually the only current uses of uranium are as atomic reactor fuel to produce electricity, to power naval vessels, or to produce plutonium for bombs. Except as it relates directly to uranium economics, mining, or milling,

the question of the acceptability of atomic power is avoided in this booklet.

There have been several significant developments since the first edition of this booklet was published in early 1980. The Minnesota Department of Natural Resources issued a report in June 1980--Uranium: A Report on the Possible Environmental Impacts of Exploration, Mining, and Milling in Minnesota. The U.S. Nuclear Regulatory Commission issued its Final Generic Environmental Impact Statement on Uranium Milling (NUREG-0706, three volumes) in September 1980. And the U.S. Nuclear Regulatory Commission published its final rules: "Uranium Mill Licensing Requirements" in the Federal Register, Vol. 45, No. 194, pages 65521-65538, on 3 October 1980.

The 1980 Minnesota Legislature has enacted a new mineral exploration law (Minnesota Laws 1980, chapter 535). This law makes provisions for certain controls on mineral exploration, including licensure by the Minnesota Department of Health. It provides for drill core data and other information gained through exploration to be provided to the Minnesota Department of Natural Resources. The law also directs the Minnesota Environmental Quality Board to review the adequacy of Minnesota's regulatory framework applicable to uranium exploration and mining. The Environmental Quality Board's exploration report is to be submitted to the Legislature in March 1981 and the mining report in July 1981. The law also imposed a moratorium on leasing state land for uranium exploration or mining until at least 1 July 1981.

Because of these recent actions of the U.S. Nuclear Regulatory Commission and the 1980 Minnesota Legislature, and subsequent Minnesota agency actions, the legal and regulatory considerations section of this booklet (pages 36-45) is incomplete. The interested reader should consult with the appropriate state or federal agency for detailed information on the current status of regulations applying to uranium exploration, mining, and milling.

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March 1981

URANIUM: AN OVERVIEW

What is Uranium?

Uranium is one of the heaviest of all metals -- a solid piece as large as a soft-drink can weighs about 17 pounds. It is also one of the most widespread. Traces of uranium are found almost everywhere -- in rocks formed millions of years ago, in coal, in ocean water, and in ground and stream water. Because it is radioactive, uranium has special significance. Uranium can be used as a fuel for nuclear reactors and nuclear weapons. The radioactivity and radioactive decay chain for uranium are described in Appendix C.

Uranium reacts chemically with many other elements under a variety of environmental conditions. Because it is soluble, uranium transfers readily from ore deposits into natural waters. Uranium usually occurs in the form of uranium oxide in the minerals pitchblende and uraninite.

Uranium in commercially significant concentrations has been found in various geological settings, including granite, sandstone, and shale. High concentrations have been found in coal and lignite, a fact that has led to the proposal that uranium could be recovered from the ash of coal-fired boilers. Uranium is, in some instances, recovered as a byproduct of other mining operations, such as gold mining in South Africa and phosphate rock mining in the United States.

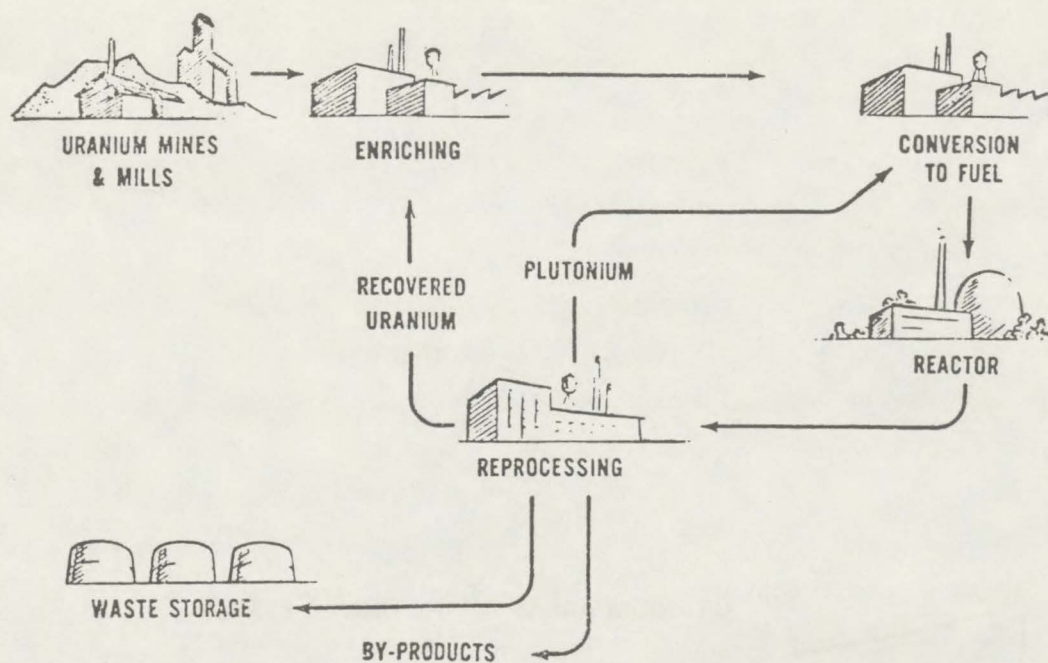
Uranium is produced in both underground and surface mines. In 1978, 42 percent of United States uranium production was from underground mines; the remaining 58 percent was from surface mines.

Uranium's Commercial Uses

In 1939 uranium was described as having no economic significance except as a coloring for ceramics. Later, uranium was suggested as a filament for lamps. Its compounds have been used for toning photographs, for staining leather and wood, and for fixing dyes in silk and wool.

The most dramatic use of uranium began in 1938 with the discovery of nuclear fission. The fission process was rapidly developed for use in weapons, but after the explosion of atomic bombs in Japan during the waning

THE NUCLEAR FUEL CYCLE



months of World War II, the United States government sought to use this awesome technology for peaceful purposes.

Now, virtually all the uranium mined commercially in the United States is destined for nuclear reactors. The military establishment uses uranium in propulsion reactors that power warships and in production reactors that convert uranium to plutonium for use in both atomic and hydrogen bombs. All commercial power reactors in this country use uranium for producing electricity. In addition, a number of reactors are used for research and experimental purposes.

The steps in producing fuel for reactors are as follows. After it is mined, uranium ore is ground, crushed, and chemically treated at a mill. In many cases, one mill treats ore from several nearby mines. At the mill, a few pounds of uranium oxide are extracted from each ton of ore. The uranium recovered at the mill is a powdery material called "yellowcake." At a different plant, yellowcake is processed into uranium hexafluoride, which is shipped to an enrichment plant where the proportion of uranium-235 is increased. Uranium-235 is the isotope that will fission in a reactor. The uranium is then converted to uranium dioxide powder and compressed into thimble-sized

pellets, which are hardened by heating in a furnace. The pellets are stacked end-on-end in long metal tubes to form fuel rods. A bundle of rods make up a fuel assembly, and these assemblies in turn form the core of an atomic reactor.

A more complete description of the nuclear fuel cycle is included in Appendix B.

United States and World Sources of Uranium

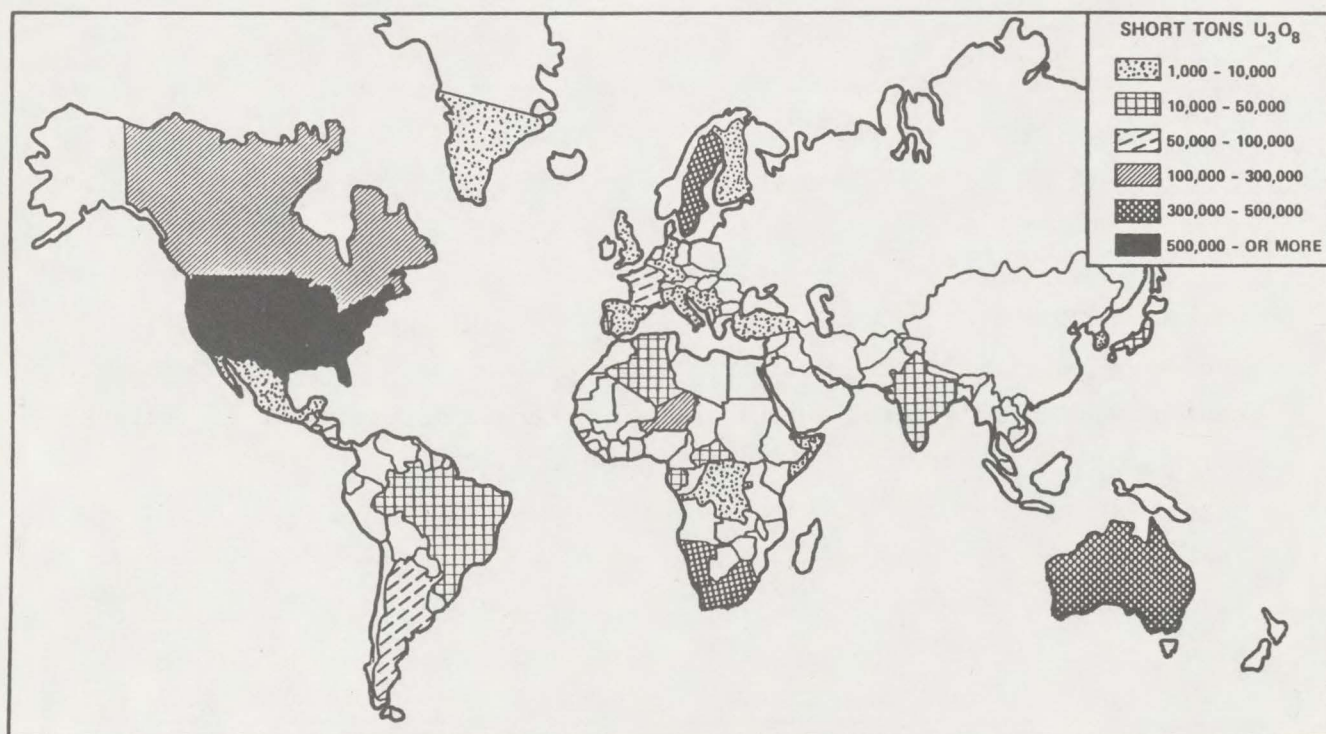
Eleven million tons of uranium ore were mined from 280 open-pit and underground mines in the United States in 1978. From these 11 million tons of ore, 19,000 tons of yellowcake were recovered.



Production capacity of the United States' 18 active uranium mills is rated at 39,210 tons of ore per day. In 1977 the Department of Energy estimated that those mills operate at 80 percent capacity.

World* Uranium Resources

REASONABLY ASSURED RESERVES \$50 PER POUND U_3O_8



*EXCLUDES PEOPLES REPUBLIC OF CHINA, USSR AND ASSOCIATED STATES OF EASTERN EUROPE

Over 90 percent of United States uranium has been produced from sandstone deposits. Other current sources are:

- In situ mining, where uranium is recovered by injecting uranium-dissolving chemicals into holes drilled in uranium-bearing deposits. These chemicals are then recovered and processed to remove the uranium which has been leached from the rock.
- By-product uranium from phosphate mining in Florida and from various copper mining operations.
- Leached uranium from old mine dumps and tailings piles. The leaching process uses chemicals similar to those used for in situ mining.

In 1977, the United States uranium industry employed 17,000 people: 24 percent in exploration, 62 percent in mining, and 14 percent in milling. The United States is the leading producer of uranium. It produced 45 percent of the world's total output in 1975. Canada is second at 25 percent, followed by South Africa at somewhat less than 15 percent, France at less than 10 percent, and Niger at 6 percent. Other significant producers (not including Communist countries) include Gabon, Spain, Portugal, Argentina, and Australia. Sweden, France, Algeria, and several other countries are also known to have extensive uranium deposits, although in some cases the ore is of such low grade that it is not economical to mine at current prices.

Uranium Reserves

Estimates of mineral reserves are usually low for a number of economic reasons, including tax laws. These estimates almost always originate with the industry involved. A company is not required to prove more reserves at a particular location than are necessary to amortize a mine-and-mill complex. Generally, as markets expand or as prices rise, an industry is motivated to look for -- and tends to find -- new reserves.

Classifying mineral resources is very technical, and methods vary for different agencies or professional groups. In general, three broad classifications are used. The most conservative is "proven" or "indicated" reserves. To be included in the proven reserve category, the presence of a mineral must have been established through drilling or other means, the

mineral must be recoverable using current mining methods, and, perhaps most important, it must be economical to mine at current prices.

Another category is sometimes called "potential" or "inferred" reserves. This category includes deposits where there is strong evidence -- either by geologic inference or because of adjacent proven reserves -- that uranium exists. Further, there must be a judgment that the mineral can be recovered with future technology and at future prices.

The final category includes "total" or "potential" resources. This category includes all known or suspected deposits of the material, but it does not necessarily mean that the uranium can be mined at any time or at any price.

In addition to these geologic and other technical factors, estimates of uranium reserves are influenced by short-term economic and political conditions. An international uranium cartel has been in existence. There have been multi-billion dollar lawsuits against uranium producing companies by a manufacturing company that had written contracts for delivery of uranium at prices which are now much lower than current rates. In addition, justifying the development of breeder reactors depends, in part, on convincing decision-makers that there is a shortage of uranium to operate conventional reactors. For all these reasons, published data on uranium reserves must be regarded with caution.

Perhaps most important, discussions of uranium resources are heavily influenced by developments in the atomic power industry. During the 1960s and early 1970s, official projections indicated rapid and continued growth of atomic power for the production of electricity, both in the United States and elsewhere. More recently these projections have been dramatically reduced, and indications are that commercial nuclear power may eventually be rejected. This possibility is crucial to the uranium mining and milling industry, because the extent of future use of atomic power will determine demand for uranium in coming years, the demand for uranium and the political geography of uranium deposits will determine future price estimates, and those price estimates will determine which uranium ore deposits are "economical" to develop.

The following table gives an indication of the uranium reserves in the United States:

\$50 PER POUND URANIUM RESERVES BY STATES
(as of January 1, 1978)

State	Ore Reserves (Millions of short tons)	Ore Grade (% U_3O_8)	Contained U_3O_8 (Short Tons)	% of Total U.S. Reserves
New Mexico	547	0.09	465,000	52
*Wyoming	478	0.06	270,000	31
*Texas	113	0.05	54,000	6
Arizona, Colorado, Utah	130	0.06	74,000	8
**Others	37	0.07	27,000	3
Totals	1305		890,000	100%

SOURCE: Society of Mining Engineers, "Uranium: A Special Report." Mining Engineering. October 1978, p. 1413.

*Estimates include reserves recoverable by solution mining.

**Alaska, California, Idaho, Montana, North Dakota, Oregon, South Dakota, Washington.

Economic Considerations

Among non-Communist countries, the United States is the largest producer of uranium and enriched uranium of nuclear-fuel quality. Therefore, politics and trends that affect the domestic uranium market bear heavily on the world market as well.

Because the demand for uranium derives predominantly from the nuclear power industry, increased growth in that industry would be expected to increase the demand for uranium. In the past several years, there have been dramatic reductions in the sales of nuclear reactors to utility companies, meaning that once the present contracts for reactor construction are completed, the demand for uranium may level off. Government policies dealing with nuclear power, the utility companies' decisions about their reliance on fission-generated electricity, and the amount of uranium discovered throughout the United States and the rest of the world will all affect the market for uranium ore.

Throughout the late 1960s and early 1970s, expectations were that the percentage of electricity provided by nuclear power would increase both in the United States and abroad. Contracts for reactors and the uranium oxide processed to fuel them are made several years in advance. Therefore, today's demand for uranium is generated not only by current market situations but by several-year-old estimates of the amount of fuel needed for reactors now in place. Current estimates of the wattage delivered by nuclear power are much lower than estimates of five years ago.

The uranium market has fluctuated considerably during the last 10 years. In 1973 the outlook for uranium producers was bleak: an oversupply of uranium oxide existed, and there were few customers for that surplus. But by 1975 uranium was suddenly extremely scarce, prices were high and rising, and there were more buyers than sellers. The market was substantially better supplied by 1976, but only after customers began to pay near-panic prices. Now, uranium exploration activity is booming, and more finds of uranium ore have been reported.

The price of uranium oxide (U_3O_8) was at a record-high \$43.20 per pound on December 31, 1977. The average price per pound of U_3O_8 during 1977 was \$19.75; in 1978 the average was \$18.50. Although the market price in mid-1979 was \$41.10, the average price received is a truer measure of the price paid for uranium by consumers during the year, because it is based on long-term contract price agreements made several years ago. A smaller percentage of uranium is expected to be delivered under contract price agreements in 1985 than 1978 (a drop from 84 percent to 34 percent), while a greater share will involve uranium production directly controlled by utilities (a rise from 6 percent to 38 percent). The remaining 28 percent will be sold under market price agreements.

Why are current prices of uranium so high? Many place the blame on an international cartel, but a more obvious reason is that the market is being forced to respond to greatly exaggerated near-term requirements of utilities for uranium. This exaggeration of uranium demand derives from a combination of interrelated United States programs and policies: a program for stockpiling low-enriched uranium and a policy of refusing to permit government customers to defer or cancel enrichment contracts entered into before the

recent reductions in planned nuclear growth. By encouraging overexpansion of uranium production, these policies and the consequent high prices may be setting the stage for a boom-to-bust cycle in the uranium industry similar to that of the 1950s.

While political decisions regarding nuclear power will effectively determine the long-term fate of the uranium mining industry, prospects are good that future uranium requirements will be met at stable or declining prices. The world outlook for obtaining sufficient low-cost uranium resources, though subject to greater uncertainty, is more favorable than that for the United States alone, because few other countries have been as fully explored for uranium as the United States. In this country, current exploration levels are high, but the industry faces tougher environmental regulations and shortages of capital. Exploration and development costs are rising at a rate exceeding general inflationary expectations. The major oil companies have recently become energy companies through the acquisition of large holdings in uranium, coal, and other energy forms. Mining companies have turned to utilities for financing as a partial solution. Utility companies, in turn, have adopted a "wait-and-see" attitude as a result of various government policies, though the current price of uranium is considered sufficient to sustain the existing accelerated exploration and development programs.

Exploration for Uranium Ores

The United States lacks an accurate overview of its uranium ore resources. To obtain more accurate knowledge, the Department of Energy (DOE) began a new survey, the National Uranium Resource Evaluation (NURE), in 1974. This effort was prompted in large part by concerns about having sufficient uranium fuel to supply the then rapidly expanding nuclear power program. The NURE survey includes three broad classes of exploration activity: aerial surveys that measure surface radiation to identify broad areas of high uranium favorability, measuring for radioactivity and other uranium indicators in surface and underground water and stream sediments, and subsurface geological investigations, for example, examining drill holes with instruments that measure radioactivity.



Examining mesa rock for uranium ore at Anaconda's mining site in Grants, New Mexico.

Uranium companies typically select favorable exploration areas using NURE data and other sources. They continue their programs with field reconnaissance, land acquisition, and finally definition and evaluation of specific target areas. To define and evaluate those target areas, uranium companies use a combination of geological mapping, geochemical surveying, and drilling.

Geological mapping involves using data from existing surface and sub-surface geologic maps supplemented by NURE data. Models are constructed for uranium deposits located in sandstone, volcanic rock, granite, and other substances in which ore is found. By using these techniques, along with computer-enhanced satellite photographs, areas of interest can be determined.

Geochemical surveying includes measuring radioactivity in rock, soil, stream sediment, water, and gas. Rock sampling aids in determining potential source and host rocks for uranium. Soil sampling is used in areas of residual soils to reveal the geochemical conditions of underlying bedrock. In this sampling technique, pathfinder elements associated with uranium often help in outlining uranium-rich areas. Ground water sampling is rapid and inexpensive but requires an understanding of regional water supplies and how they are influenced by subsurface soil and rock structures. This method is best suited for large or populated areas when extraordinary or abnormal amounts of helium, radon, radium, uranium, and bicarbonate and sulfate ions in the samples may indicate the presence of uranium deposits. Stream sediment sampling reflects an area's watershed characteristics. Gas samples, mainly radon and helium, in the soil, water, or air, can be measured with some success in detecting the presence of uranium. While these samples can be easily analyzed with modern equipment, the ease of diffusion or migration of the sampled matter can make the results difficult to interpret.

Geophysics is used to identify host rocks that may contain uranium deposits. A radiological analysis involves surveys of radioactivity resulting from disintegrating uranium or uranium daughter products such as radium.

Testing for subsurface radioactivity by drilling, electrical logging, and analysis of the drill core represents the final phase of the exploratory activity. Measurements of the radioactivity in the ground and chemical analysis of the core are used to estimate the amount and grade of uranium in the ore.

Uranium exploration is being carried out in all the major ore-producing areas in the United States, most of which are west of the Mississippi River. According to the Department of Energy, the recent accelerated pace of exploration was greatly influenced by continuing favorable market conditions, which encouraged high spot prices, and by announcements of important new discoveries. These and other factors caused exploration companies to speed up the search for new deposits in both sandstone and non-sandstone areas.

In the United States the presently and potentially important areas under investigation include:

- The Powder River Basin in Wyoming, which leads in drilling activity in the United States.
- The Grants mineral belt and San Juan Basin of northwestern New Mexico.



Testing new uranium detectors developed by U.S. Geological Survey scientists. The device is lowered into a drill hole to search for deeply buried uranium deposits.

- The Uravan mineral belt of southwestern Colorado and southeastern Utah, where additions to known ore deposits are being discovered.
- The Texas Coastal Plain, where drilling continues in the vicinity of known deposits.
- Colorado's intermountain basins, where discovery of a major deposit at Tallahassee Creek has intensified exploration for sandstone host rocks.
- Western Arizona, where large deposits have been discovered, particularly at Date Creek.
- Northeastern Washington, where the Midnite mine is being used as a model for exploration along the margins of batholiths in the Northern Rockies.
- Throughout the Basin and Range of Oregon, Nevada, Utah, and Arizona in formations similar to the McDermitt area of Nevada, where recent discoveries were announced.
- Minnesota, Michigan, and Wisconsin, where exploration is active in the southern Canadian Shield.

Uranium Mining

Large-scale uranium production facilities were initially established in the United States to supply materials for weapons and other military purposes. The Atomic Energy Commission was the sole purchaser of domestic uranium in the early 1950s. To become free from dependence on foreign supplies, the commission guaranteed a minimum price and directly supported the growth of the uranium mining industry. The AEC also conducted exploration programs in conjunction with the United States Geological Survey and state geological surveys and offered production bonuses and other incentives that stimulated private exploration and mine development. As a result of such encouragement, the nation underwent a uranium boom in the late 1940s and early 1950s. Heightened exploration and development occurred again in 1966 and, most recently, in 1977.

Although open-pit uranium mines have produced large quantities of uranium ore, a high percentage of known reserves occur at depths too great for surface mining. Consequently, underground mining will increase.

Underground uranium mining operations include service buildings, a head frame with a track-loading facility, a mine waste pile, and a flow of water

from underground sumps pumped to the surface for use in the mill and concentrator. The area occupied by the hoisting and loading facilities, shops, warehouse, changehouse, and office may be only a few acres, but the reach of underground openings may be a mile or more. The volume of mine waste taken from these tunnels and shafts can be 60 percent more than the volume of uranium ore removed through them.

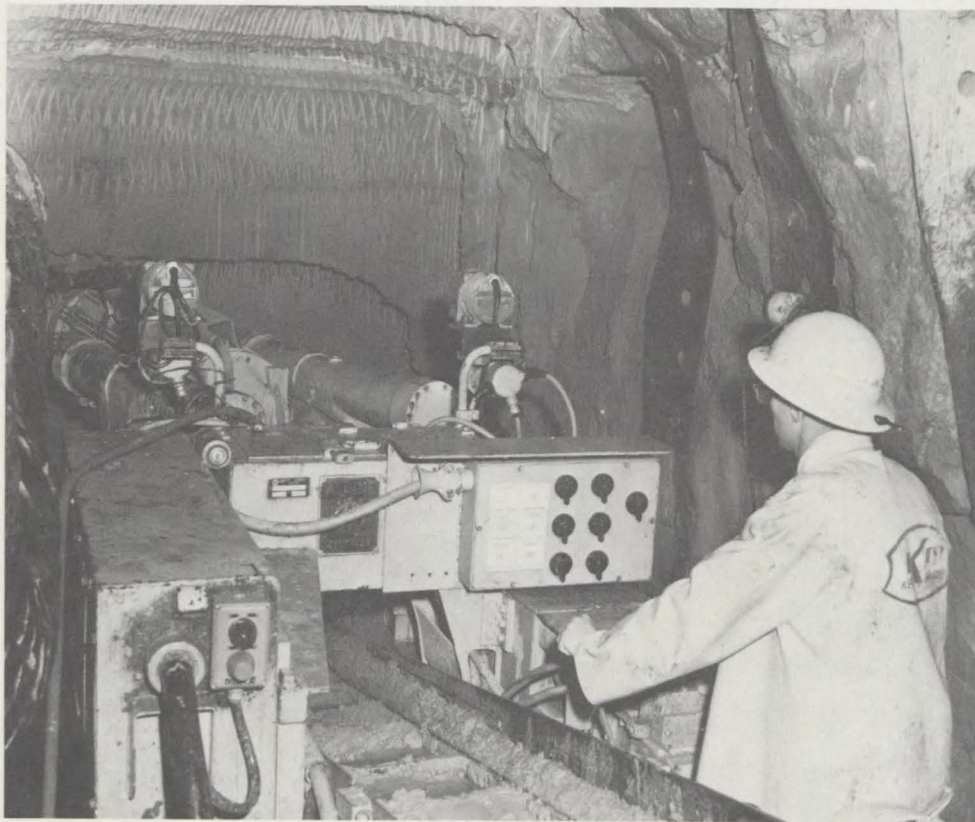
Most uranium ore deposits are long but not thick, and this configuration requires special adaptations of routine mining methods -- highly mobile blasting and mining techniques, for example -- to permit inexpensive and rapid digging.

Ground water that enters underground uranium workings contains a variety of dissolved material, including radium, radon, and uranium. As it travels through the mine to the collecting sumps, the water is likely to release radon gas into the mine air and may gain slightly in uranium content. In some operations, it is economically feasible to recover uranium from this waste water.

Radon gas has been proven to be the cause of excessively high numbers of lung cancer deaths among uranium miners,* so uranium mines must be well ventilated. Fresh air is usually directed downward through the production shaft, ducted to a mining face, and returned through ore haulage ways where it is discharged through vent holes or shafts. The discharged mine air may contain significant quantities of rock dust and radioactive gases.

Where the ore is sufficiently close to the surface, open-pit mining of uranium is done. Open-pit mining is characterized by a large, open excavation, large piles of earth and rock overburden placed nearby, a network of operating roads and yards, and a flow of mine water pumped into a settling pond. Because pollution control standards place a limit on the amount of radium in surface waters, the waste water is treated to precipitate radium before the water is discharged into the ponds. Uranium mills, shops, the warehouse, office, changehouse, and an assortment of heavy earthmoving equipment are nearby. Depleted pit areas are sometimes converted to small artificial lakes, although the use of those waters for recreation and other human activities may be limited.

* There is a brief discussion of the human health effects associated with exposure to ionizing radiation in Appendix D.



Underground mining near Grants, New Mexico.

To the extent that uranium mining is similar to other kinds of hard-rock mining, the occupational risk of accidents is similar as well. Deaths from underground uranium mining accidents occur at a rate of about 15 per 10,000 miners; this does not include any cancers, other diseases, or injuries associated with exposures to radon gas and other radioactive materials. Open-pit mining, devoid of the hazards of underground mining, results in fewer accidents and deaths.

Because uranium is radioactive, underground miners are exposed to a special hazard. Uranium ore constantly undergoes radioactive decay to radium. Over time, radium decays to a radioactive gas, radon, which seeps out of the rocks and into the mine air. Radon gas rapidly decays to a variety of highly radioactive particles, "radon daughters," which cling to ever-present dust particles and water droplets in the mine air. Radon and the radon daughters are breathed by the miners and may become trapped in epithelial tissue in the lower respiratory tract. The radioactive energy emitted by these particles is the source of lung cancers, fibrosis, and lymphatic cancers.

The ventilation systems now mandatory in all uranium mines have reduced, but not eliminated, the miners' exposure to these radioactive gases and particles. However, these safety standards did not always exist. In what was one of the most tragic chapters in American mining, several thousand underground uranium miners were significantly and needlessly exposed to radioactive gases, before those standards were adopted. The health of some 3,400 white and 780 nonwhite (mainly American Indian) uranium miners was followed carefully from 1950 to 1968, and less rigorously from 1968 to the present. By 1973 more than 180 respiratory malignancies were reported, and the current total of excess lung cancer deaths is estimated at 250 to 300. Predictions of 600 to 1,100 ultimate deaths due to this irradiation have been made for this group. The hazard to miners has been reduced by the more stringent standards that now apply to radon concentrations in mines.

In addition to these radiological dangers, uranium mining has impact on the environment -- in water, in the air, and in solid wastes.

A significant environmental impact associated with uranium mining results from the dewatering of either underground or open-pit mines. Mining, by its nature, significantly modifies the normal ground water flow cycle below the water table. Dewatering is accomplished either by a ring of dewatering wells or the use of sumps within the mine, or by a combination of



Open-pit mining in Wyoming (top) and New Mexico (bottom).

those two methods. The lower water table can result in exposing mineralized rocks to a new environment, which can in turn affect the geochemical structure of those rocks and lead to increased oxidation and the dissolving of radiochemical and toxic materials. In addition, radium-226 and other minerals, some of which are toxic, are leached from the mine water as it flows through the mine to the sumps. Ammonia is also present in the mine water, due to the use of ammonia blasting agents. In open-pit mines, precipitation falling on the exposed ore and waste rock can leach radiochemical and toxic pollutants.

Although claims have been made that pollutants in mine water represent natural conditions and should not be controlled, regulatory agencies (namely the U.S. Environmental Protection Agency) have disagreed for the following reasons: 1) if the mines were not operating, the contaminated water would not be discharged to the surface for later uptake of pollutants by the biosphere, and 2) mining activities increase exposed surface area, lower the water table, and contribute to other conditions conducive to the dissolution of pollutants from mineral solids.

Local air quality is also affected by uranium mining activity. The vent shafts, which serve to flush the mine air for the underground miners, can pose a problem for nearby residents. Estimates of the magnitude of the ever-critical radon emissions from the vented air vary greatly. Earlier studies, noting the remote location of most uranium mines, generally concluded that population exposures were negligible. Recent studies have concluded differently. Radon gas decomposes rapidly, and several of the resulting radioactive daughter isotopes appear to enter the food chain. Perhaps more significantly, the problem is critical where nearby homes are occupied by workers exposed to the same radon byproducts during working hours.

Dust from ore transport can pollute the air and can result in a radioactive strip along the haulage roads. In general, the ore loss along these routes is not pronounced.

Waste rock containing uranium minerals of too low a grade to constitute ore can present a potential for long-term radon emissions and dissolved toxics in surface runoff. Control practices range from no regulation whatever in some operations to covering the waste with a pad and using an extensive water treatment system on runoff from the pile. This problem, like

that of management of the uranium tailings, is not yet resolved. Because of the long life of the radioactive materials involved, the hazards persist for thousands of years.

In addition to these environmental impacts due to the radioactive nature of uranium ores, there are other environmental impacts, including land use, siltation, noise, and conventional air and water pollution, that are similar to those from other types of mining.

Uranium Milling and Tailings

Mined uranium ore typically contains a few pounds of uranium oxide (U_3O_8) per ton of material. To extract the usable uranium oxide, the ore must be milled in a process similar to concentrating processes used in other types of hard-rock milling. Because of important economic factors, such as haulage costs, uranium mills are located near the sources of the ore.

A typical uranium processing mill is a complex of buildings similar to, but smaller than, those found in taconite-processing operations in northern Minnesota. They contain crushing machinery, receiving bins, screening operations, conveyors, and a chemical-treatment facility.

The uranium ore is crushed, ground, and leached (by percolating liquid chemicals through it) to dissolve the uranium minerals from rock. The leached uranium-bearing solution is separated from the undissolved material and uranium is recovered as a chemically precipitated concentrate. Then this concentrate is roasted, pulverized, and drummed for shipment as a powdery material called "yellowcake." The wastes, known as mill tailings, are a slurry of finely ground solids in waste solutions. The slurry is transferred to a tailings pond where the tailings settle into a pile.

The radioactive content of the tailings is about 85 percent of the radioactivity of the original uranium ore. A few percent of the uranium initially present in the ore remains in the tailings, as do most of the uranium decay products which were in the ore. Radium-226 is the most hazardous nuclide in the tailings. The quantity of radium and radon in the tailings will diminish by only one-half in roughly 80,000 years.

During 1978 and 1979 an Interagency Review Group (IRG), appointed by the President, studied all aspects of radioactive waste management, including the management of tailings from uranium milling. The IRG was composed of

senior representatives from all federal agencies with jurisdiction over radioactive wastes. The IRG concluded in its March 1979 report that management of radioactive waste products at mill sites has been poor in the past, and that considerable research and development must still be done.

The IRG stressed that because of the very long half-lives of radium and other radioactive materials in the mill tailings, "these waste streams may present problems of comparable magnitude [to the high-level radioactive wastes produced by atomic reactors] for the very long term, that is, beyond a period of a thousand years." They concluded that "disposal of these tailings must be managed as carefully as that for the high-level wastes."

"The ultimate objective," the IRG report states, "should be to dispose of the tailings in such a manner that emissions of radon and radium are reduced to [background levels] or as near background levels as can be reasonably achieved, and that no active institutional care be required to keep the tailings isolated from people following disposal." The IRG noted that there



Uranium mill in Texas shows crude ore piled in foreground. It will be crushed and screened in tower at left before processing for recovery of uranium.

have been two general methods proposed for future containment of the tailings: "The first involves covering the tailings with one of a variety of materials to reduce erosion and radon release. The second involves placement of the tailings below ground level in mines or open pits."

Many other studies have concluded that uranium mill tailings must be as carefully managed as the highly radioactive wastes from other portions of the nuclear reactor fuel cycle. The Congress, too, has recognized that the past record of control at mill sites has been poor and that little or no attention has been given to the problem of proper disposal of tailings. In 1978, Congress passed an amendment to the Atomic Energy Act, the Uranium Mill Tailings Radiation Control Act. This act, and action by the Nuclear Regulatory Commission and the Environmental Protection Agency, are leading to a complete review and revision of the various steps involved in the management of tailings, which are now formally recognized as radioactive wastes.

As the IRG points out, the ultimate objective is to dispose of the tailings in a manner that reduces emissions of radioactive materials to as low a level as can reasonably be achieved, and that no active care be required to keep the tailings isolated from people for periods of many thousands of years.

The Nuclear Regulatory Commission has completed a Draft Generic Environmental Impact Statement (GEIS) on uranium milling. A final environmental impact statement should be published in 1980. Both technical and institutional issues are addressed in the draft impact statement. The Nuclear Regulatory Commission outlined the following major technical issues: 1) isolating tailings for long time periods, 2) controlling airborne emissions (particularly radon), 3) protecting ground water quality, 4) decommissioning mill structures and sites, and 5) nonradiological environmental impacts and resource use. The NRC also cited a need for land use controls and site monitoring, as well as financial surety for proper waste management, and funds for any long-term surveillance of disposal and site decommissioning measures.

In carrying out its evaluation, the NRC compared several alternative methods of tailings management with a "base case." The base case represents most past milling practices. In making this comparison the NRC points out:



Aerial view of inactive tailings pile at Monument Valley, Arizona.

Close up of same site showing perimeter fence on left almost covered by windblown tailings.

"...analysis of the base case brings into sharp focus the potential environmental and public health impacts which can occur."

In their summary of the "base case" uranium mill, the NRC concluded that the odds that a human being will die prematurely of cancer due to the proximity of his residence to a uranium mill for a period of 20 years (the period now assumed to include the full operation and decommissioning cycle) are about 600 in a million. The statement pointed out that the margin for error of this estimate was large -- actual figures could be from half to twice those estimated. "Comparison with the risks posed by background radiation," the GEIS said, "provides valuable perspective. The estimated risks to the nearby individual would be an increase of about 40 percent above risks from background radiation exposures."

Further, the NRC concluded, people living in a region where maximum milling and mining are carried on face, by the year 2000, a risk roughly double that posed by milling activity alone. In evaluating the occupational risks, the NRC estimated that average annual occupational exposures are 2,090 millirem to bone and 4,740 to lung, an exposure level leading to a lifetime risk of premature cancer death of about one in 50 with a given work period of about 50 years. This is about six times the risk due from natural radiation exposure. For the general population, the NRC said, "The most significant impact from mill operations under the base case would occur from persistent radon releases from the tailings. About 9800 premature deaths are predicted over the period 1978-3000 in the United States, Canada, and Mexico, from tailings which would be generated by the full operation of mills in existence in the U.S. in the year 2000."

The Draft Generic Environmental Impact Statement describes radiological and non-radiological impacts in detail. It must be stressed that the base case used for comparison is regarded as typical of past practices, and that these base case impacts are more serious than should be the case with new mills or any existing mills which have been upgraded. Also, the NRC's analysis is for a semi-arid region typical of actual regions in the western U.S. These obviously, are not the conditions that exist in Minnesota. There are no formal plans for a detailed evaluation of impact factors involved in uranium mining and milling in Minnesota.

Several alternative methods for treating and disposing of mill tailings are evaluated in the NRC's draft impact statement. These include various degrees of treatment of the tailings to remove the radium, thorium, and more of the uranium, ways to stabilize tailings piles, and methods for placing the tailings underground.

An environmental impact statement usually includes an economic analysis of the various alternatives and a recommendation based on the results of that analysis, as well as on a consideration of the environmental impact of each method. In the case of the NRC environmental impact statement on uranium mill tailings, however, the economic analysis was not done. In explaining why this was the case, the NRC stated:

The staff considered, but decided it would not be reasonable to attempt making, a fully "monitized" balancing of costs and benefits in recommending the proposed limits on radon attenuation, which is a very long-term problem. Such balancing has been done in some past cases where effluent standards have been set primarily for radionuclides of relatively short half-lives. For example, in limited cases, potential cumulative health effects from releases have been assigned monetary value and weighed against predetermined criteria on costs to avert them in deciding how much control is enough. The staff chose not to invoke such rigorous cost benefit balancing because, while it appears to offer a "rational" approach to standard setting and to avoid arbitrariness, it is inevitable that arbitrary judgments and assumptions must still be made. This is particularly true in the case of radon from tailings because of the uncertainties associated with the very long-term nature of the hazard. Furthermore, such a cost-benefit approach would constitute an oversimplification of the tailings disposal problem, which involves many interrelated matters, and as such would be misleading.

Factors which will ultimately determine how many real effects will occur, and on which there is large uncertainty, include such things as: future population sizes and distribution, impacts of changes in climate (such as heating of the earth's atmosphere, the greenhouse effect), scientific advances (which might include a cure for cancer), and long-term performance of tailings. These uncertainties compound those existing in computational models used in estimating costs and effects. Notwithstanding this, scenarios can be postulated for future events to provide a basis for estimating effects and costs.

Throughout the document, the staff has presented information which would allow readers to construct their own scenarios and, thus, draw their own conclusions about the issues being discussed.

If the estimates of long-term effects are accepted, selecting a level of control will still require making arbitrary value judgments in answering several important questions. First, when weighing committed long-term impacts against costs to control them, over what period of time should the impacts be considered? Should it be 100, 1,000, 100,000 or 1,000,000 years? Obviously, by selecting different time periods, almost any amount of money for control of radon could be 'justified.'

Second, there is the question of deciding how much adverting a health effect ("life" or "life shortening" in the case of a premature cancer death) is worth in monetary terms; that is, of deciding what the cost-benefit decision criteria should be. It would be difficult to decide the worth of health effects today and more difficult to decide the value of future effects (that is 1,000, 100,000 years and beyond). Does a premature loss of life 100,000 years into the future have the same value as a life today? Although there has been continuing discussion in public and professional forums on the desirability of rigorous cost-benefit procedures, there have been no answers or common acceptance of resolutions to these underlying questions and uncertainties to allow invoking such rigor, particularly for long-term hazards.

U.S. Nuclear Regulatory Commission, office of Nuclear Material Safety and Safeguards. Draft Generic Environmental Impact Statement on Uranium Milling, (NUREG-0511) Project M-25 April 1979 pp 18-19.

The control of radioactive waste is not the only environmental issue associated with uranium mining and milling; it is only the most difficult. The more conventional issues are those associated with land use, air and water, noise, energy use, and others. These must also be considered for uranium mining and milling, just as they are for other mining and milling operations.

The radium and radon problems of uranium mill tailings illustrate the underlying difficulties of managing radioactive wastes in general. The hazard is a long-term one, extending over hundreds of thousands of years. Exposure to radiation is known to cause cancer and genetic damage. The impact per human generation may be relatively small, but the cumulative impact

is large. Expenditures to manage the tailings (for example, chemical treatment to remove the radium, thorium, and residual uranium, developing methods to dispose of those elements safely, and placing tailings underground in a way that ensures they do not contaminate the circulating ground water) must be incurred at the time of milling, while most of the benefits of fewer cancers or genetic mutations would not be realized for a long time. These "value judgment" decisions emphasized by the NRC must be made prior to mining and milling.

Present environmental and NRC regulations require tailings to be disposed of in a natural basin sealed with an inactive clay or bentonite seal. These basins need to be able to hold the watershed from a 100-year flood cycle. However, as indicated in the NRC draft impact statement, the adequacy of these current regulations is now being examined. Present measures are now regarded as possibly being adequate for the short term, but because the hazards persist for up to thousands of years, accepting those measures only postpones implementation of really long-term safe management. Pending completion of the current reevaluation, the requirements for new mines and mills cannot be stated.

An alternative to conventional methods of recovering uranium resources, in situ leaching, has recently been introduced. Wells are drilled in a uranium deposit, the rock is blasted at certain depths, circulating chemicals are injected into the ore-bearing rock, and the desired solution is pumped out via production wells. Uranium is then separated from the leach solution by conventional milling-unit operations.

When this method is used properly, there is adequate control of leach solutions to prevent them from escaping into the circulating ground water. Furthermore, in certain situations the locale can be restored to earlier water-quality conditions or to applicable standards, whichever are higher.

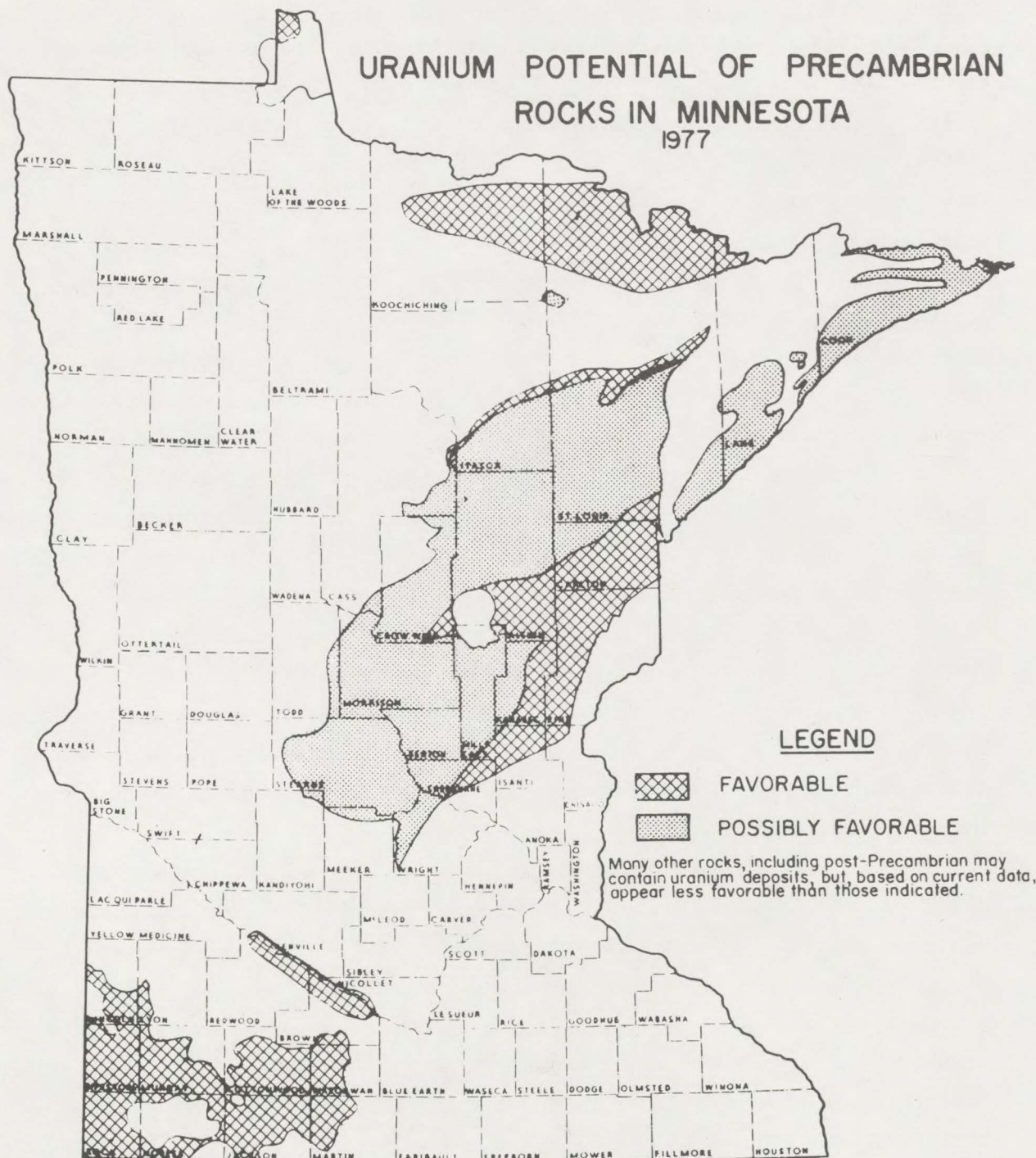
Unlike conventional milling operations, in situ leaching requires no ore mining, transportation, or grinding. Moreover, the process of extracting the solution does not produce conventional mill tailings. It does, however, produce solid and liquid wastes that require controlled disposal. These wastes are primarily precipitated calcium, coprecipitated uranium, some thorium, and spent resin from ion exchange columns. With this method,

less than five percent of the radium from an ore body would be brought to the surface. The wastes from in situ leaching operations can be disposed of by a method similar to that used for conventional tailings piles or through deep-well disposal or reinjection.

In situ mining operations do, however, produce some hazardous surface wastes that require controlled disposal; they may also pose a hazard to underground water supplies.

In situ leaching is currently being used only in poorly compacted sandstone deposits with high permeability. The areas of exploration in Minnesota's Carlton and Pine counties lie in highly compacted materials with low permeability.

URANIUM POTENTIAL OF PRECAMBRIAN ROCKS IN MINNESOTA 1977



Potential areas based on R.W. Ojakangas, 1976, U.S.E.R.D.A. Contract AT (05-1)-1652

RECENT DEVELOPMENTS

Uranium Exploration in Minnesota

The first significant exploration activity in Minnesota was directed by Dr. George M. Schwartz in 1949. Schwartz, then head of the Minnesota Geological Survey, was awarded an Atomic Energy Commission contract to search for radioactive vein deposits of the kind discovered in Ontario east of Lake Superior. Measurements were made at more than 200 locations. Few indications of abnormal radioactivity were found.

A rash of prospecting occurred in the mid-1950s during the nation's uranium boom. Drilling was done in a few places, including the Littlefork area and the Northwest Angle. The Minnesota Department of Natural Resources had a program of exploration leases on state land at that time; most of the leases issued were for the northern portion of the state.

Atomic Energy Commission personnel conducted a general survey of uranium favorability in the Lake Superior region in the 1960s, and in the early 1970s two studies were done involving the actual measurement of thorium and uranium in rocks in northern St. Louis County. In 1976, Union Carbide Corporation's Nuclear Division conducted a geochemical survey in east-central Minnesota, specifically in the Barnum area, under contract with the Department of Energy as part of its National Uranium Resource Evaluation program. Denison Mines, BurWest (Burlington Northern), Rocky Mountain Energy Company, and perhaps other mining companies were also conducting surveys in the area at the same time.

The study by Richard Ojakangas released in October 1976 caught the public eye and focused serious attention on the potential for uranium mining in Minnesota. By spot-checking for radioactivity, reviewing the geologic structure, and comparing Minnesota locations with uranium-bearing formations in Canada and elsewhere, Ojakangas concluded that several areas warranted further investigation for their uranium potential. His report listed several abnormally radioactive sites: the Northwest Angle; the Big Falls to Lake Vermillion area; the St. Cloud, Staples, Sartell area to east of Mille Lacs Lake to Denham; and the area from Cloquet and Carlton to Moose Lake and Willow River. Of special interest is the Thomson formation in the Barnum-

Moose Lake area, where a sample of material contained eighteen parts per million of U_3O_8 , sufficiently high to justify the exploratory advances made so far. Ojakangas noted that due to a thick cover of glacial material and a long history of surface leaching, exploration for uranium in Minnesota is especially difficult.

Several companies have leased private lands for exploration of uranium, and others are just now moving onto the scene.* The most active company, based on leasing activity, is the Rocky Mountain Energy Company, a division of Union Pacific Corporation, headquartered in Denver. This company opened a district office in Barnum after beginning its initial investigations throughout Minnesota, Wisconsin, and Michigan in 1975. Operating with monies invested by Southern California Edison, Rocky Mountain Energy Company has acquired roughly 95,000 acres of private leases in Carlton, Pine, and Kanabec counties. It has conducted extensive well water and lake sediment sampling programs as well as aerial and ground radiometric surveys. Between December 1977 and May 1979, Rocky Mountain Energy Company drilled 41 holes.

Another company, Martin-Trost Associates, is in partnership with a wholly owned subsidiary representing a group of power companies. This company began exploration in Minnesota in March 1977 and started acquiring land a year later. As of late February 1979, it had leased over 20,000 acres in Carlton and Aitkin counties and drilled several holes. Martin-Trost Associates, whose home office is in Golden, Colorado, maintains an office in Moose Lake.

Energy Reserves Group, Inc., also based in Golden, Colorado, is a coal, oil, gas and uranium exploration and development company, but is not under contract to any utilities company. Although it does not maintain an office in Minnesota, this company has leased at least 15,000 acres in Pine and Carlton counties and has drilled several exploratory holes on those lands. It is not drilling currently and has slowed its exploration pace.

A fourth company is a German corporation, Urangesellschaft U.S.A., Inc., which has leased more than 1,000 acres in Carlton County and has acquired several leases in Benton County through the office of Wirt L. Harris Company, a land broker. This company currently is performing ground follow-up to a 1978 aerial survey and anticipates drilling at least two holes when preliminary analysis is complete.

*Since the first edition of this booklet was prepared, Marathon Resources and Exxon have begun exploration in southwest Minnesota. Leasing activities are also underway near Aurora-Hoyt Lakes in the Iron Range.

The Anaconda Company - Mineral Resources Group of Denver, Colorado, the Phillips Uranium Corporation of Albuquerque, New Mexico, and Exxon Minerals, U.S.A., of Denver were in the early stages of securing land leases in early May 1979.* These companies are all relative newcomers to the exploration race in Minnesota and have reported little to state agencies regarding their activities. The Minnesota Department of Natural Resources, lacking legal authority to compel exploration companies with private leases to register with them, routinely mails questionnaires to companies they have reason to think are leasing and drilling anywhere in the state.**

The major concern of state agency personnel with drilling operations is the fear that local water supplies will be contaminated with radioactive material. While any uranium ore presently in the ground may already pose this threat, the drilling may bring other water sources into contact with this material. Most of the companies known to be drilling have expressed a willingness to plug the holes, although no statutory authority now exists in Minnesota to require proper abandonment of exploratory drill holes.

High concentrations of radon have been found recently in some water wells in east-central Minnesota. It is not known whether these levels are occurring naturally or if they have been caused in some way by exploration drilling activities.

Uranium Development in Other Places

What does uranium mining mean for the Minnesota locations that have attracted exploration attention? How should the state government react to this potential? Is there a possibility of commercial mining and milling of uranium in Minnesota?

As we in Minnesota face these and a host of other questions about uranium mining, we may find that some of the problems we encounter here have been encountered elsewhere. To illuminate the policy issues that may be

* Other mineral exploration is underway in Minnesota as well. The Blue Waters Oil and Gas Company has one lease for oil and gas in Pope County. Exxon Minerals Company owns two or three dozen leases in Norman County and four leases in Mahnomen County for base metals. Union Carbide Minerals also has at least one base-metals lease in Lake of the Woods County.

**This has been changed by the new mineral exploration law passed by the Minnesota Legislature in 1980. See the Introduction, page viii, of this booklet.



URANIUM MILLS IN THE UNITED STATES OPERATING AS OF 1/1/79

raised about uranium development, this section will mention a few examples of uranium development in other states and countries.

Red Rock, Arizona, is a small town in the northern tip of the Navajo Nation, the largest reservation in the United States. The Red Rock area is a good place for studying cancer and fibrosis because it has a near zero cancer base rate, which means that, by and large, Navajos do not get lung cancer.

In Red Rock, huge piles of uranium mill tailings lie within a stone's throw of several homes. Also, many of these same houses were constructed of materials made with uranium tailings. Because of their proximity to Navajo communities, including Red Rock, the radioactive tailings piles are a serious health threat. The Department of Energy has estimated that it will cost 20 million dollars to clean up the 10 million tons of tailings left on the reservation. The department also reports increased lung cancers among residents of nearby communities.

The Red Rock area is adjacent to a uranium "hot spot" in northwestern New Mexico. According to environmental impact statements, a small community like Crownpoint, New Mexico, can expect its population to soar to 15,000 in five to ten years, a 500 percent increase. And, according to the United States Geological Survey, the new uranium mines will seriously deplete the area's water supply.

Uranium mill tailings have been used for construction in Grand Junction and Denver, Colorado; in Salt Lake City, Utah; and in Cannonsburg, Pennsylvania. The public health dangers of such construction were made acutely apparent when Congress passed legislation in 1972 to remedy the problem in Grand Junction.

Over 25 million tons of uranium tailings have accumulated at inactive mill sites, and "...at none of these sites," according to the Interagency Review Group report, "can the tailings be considered adequately stabilized for long-term storage. Contamination usually extends beyond the property boundaries due to wind or water erosion. In Durango, Colorado, for example, dust from a nearby tailings pile is said to have blanketed homes. And on Utah's Green River, a flash flood washed 14,000 tons of tailings downstream in one of the 16 known accidental releases of tailings since 1959.

In addition to tailings at inactive mills, 119 million tons have piled up at operating mills, and they will continue to pile up at a rate of approximately 10 to 15 million tons annually. Although new technologies can be incorporated into standard operating procedures in an attempt to alleviate problems with the tailings, the best technologies are not easily selected or implemented.

Reclamation or mined land has been a problem in states where some uranium mines have not backfilled their open pits properly. Colorado and Wyoming now have laws that require improved performance by mine operators.

In 1978, New Mexico's Senator Peter Domenici introduced a uranium miners' compensation bill that was similar to the legislation providing benefits for coal miners afflicted by black lung disease. Miners, their families, and survivors of deceased uranium miners have been trying to get workmen's compensation for occupational deaths and illness since 1971. Domenici's bill failed to pass during the last session, but renewed Senate subcommittee hearings and a revised bill sponsored by Domenici promise some hope for hundreds of families.

New uranium development has created stirs of protest in South Dakota's Black Hills, where one million acres are under exploration. The Tennessee Valley Authority and Union Carbide Corporation are two of several companies that have leased more than 190,000 acres for open-pit and underground uranium mining operations. The Black Hills area has become the target for uranium, coal, and iron ore interests because of its obvious mineral wealth. But the water resources of the area are limited and are already in demand by communities, farmers, and ranchers. Mining and milling activity would reduce the supply of water available to these people.

Uranium mining development in other countries, including Sweden, Australia, and Canada, has also caused controversy. In Australia, deposits said to be among the richest in the world threaten ancient aboriginal lands.

A Canadian board of inquiry was established to investigate the consequences of the proposed development of a new uranium mine at Cluff Lake in northern Saskatchewan. The province of Saskatchewan had two existing mining operations when the investigation began in 1977. One comprised a number of underground mines at Uranium City that have been mined commercially since the 1950s; the other is an open-pit mine at Rabbit Lake.

The board of inquiry addressed nine issues: 1) radioactivity and the biological effects of radiation with reference to existing standards, 2) the health and safety of workers, 3) environmental considerations, 4) national and provincial control arrangements, 5) general economic and social effects, 6) the North (the communities of northern Saskatchewan and problems unique to them), 7) the safety and disposal of nuclear wastes, 8) nuclear proliferation and terrorism, and 9) moral and ethical issues in the development and use of nuclear energy.

The Cluff Lake Board of Inquiry concluded in its 1978 final report that the new uranium mine and mill would not present undue hazards to the people of Saskatchewan, if all environmental and health and safety regulations are adhered to and constantly monitored. Further, the board found that the threat to world peace due to nuclear proliferation and terrorism would not be exacerbated by development of those resources, thus presenting no reason for withholding Saskatchewan's uranium from the world market. The report closed by noting that moral obligations fall on industry, government, Canadian citizens, and human beings in general for the continued stability of the nuclear fuel cycle.

Obviously, a wide range of policy issues and opinions characterizes the topic of uranium mining development.

LEGAL AND REGULATORY CONSIDERATIONS*

Local Governmental Authority to Regulate Uranium Mining

One possible source of uranium mining regulation may be governmental action by Minnesota communities, counties or other local units of government. These local units may, in the exercise of their police power to regulate and promote the general health, safety, morals, and welfare of the community or unit, carry on planning and zoning activities. Under statutes passed by the State Legislature, local units of government have been given the power not only to engage in zoning activity, but also to develop comprehensive planning for the area by means of an ordinance which may then be the basis for specific land use zoning. Uranium mining could be the subject of regulation under zoning activity with respect to a particular use or as part of the zoning activity that is undertaken pursuant to a comprehensive plan where such plan has been adopted by the local unit of government. Zoning permitting a particular use or forbidding a particular use (such as commercial, industrial or residential uses) can be undertaken. Arguably, uranium exploration or mining could also be subject to such an exercise of the zoning power. However, such zoning must be related to promoting the general public health, safety, or welfare.

Exercise of the zoning authority by local units of government must meet several requirements in the event that it is subject to a legal challenge. First, the zoning must be for a proper public purpose. Second, there must be a rational basis for the zoning. That means that a reasonable relationship must exist between the zoning provisions and the purpose for which the zoning has been undertaken. Third, the zoning activity must not be arbitrary, capricious, or unreasonable, nor may it be confiscatory. As long as the zoning operates uniformly upon all landowners similarly situated, and a proper public purpose has been undertaken in the zoning activity, the ordinance is likely to be upheld. Fourth, where a comprehensive plan for the area is in effect, the zoning activity must be in conformance with the comprehensive plan.

In addition to the above considerations, challenges to zoning activity have on occasion examined the reliance by a person upon a particular zoning

*Certain portions of this section of the booklet have been rendered incomplete by legal and regulatory changes at both the Minnesota and federal levels since the first edition was prepared. See the Introduction, page viii, for details.

classification. Thus, where a user of land, such as a person engaged in uranium exploration or mining, has incurred obligations and expenses sufficient to create a vested interest in such a use, this reliance may preclude the adoption of new zoning regulations limiting the use to non-mining purposes. Balanced against this consideration, of course, would be concerns revolving around the possibility of hazards to the public health, safety and welfare as well as environmental integrity which might justify altering the use and restricting the activity permitted on the land.

Finally, it should be noted that local units of government have the power to adopt "moratorium zoning" ordinances for limited durations (up to two years) provided they are enacted in good faith and without discrimination. Such interim zoning is permissible for the purpose of allowing the local unit of government to study the intended uses proposed for the land or for the purpose of considering a comprehensive plan or other official controls which might be adopted to serve the public interest. The interim zoning best fulfills the function of providing time for considering planning. It does not serve as a vehicle for permanent long-term zoning in itself.

Minnesota Laws and Regulations

Minnesota's state agencies, for the most part, are not yet equipped with special uranium mining regulations. No single agency in Minnesota has complete authority to regulate uranium exploration, mining, and milling. Many agencies, both at the state and local level, have some authority; a list of permit authorities, prepared by the Department of Natural Resources, is included as Appendix E. Partly because of unresolved issues presented by 1978 federal legislation on uranium mill tailings, some governmental units are not certain what their role should or could be in the regulation of uranium mining development and operations. Which Minnesota agencies will be most active depends, to a certain extent, upon where the development might occur, who owns the land, the degree to which state authority may be preempted by federal action, and possible new actions by the Minnesota Legislature. It seems clear, however, that the Minnesota Executive Council, the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency, and probably the Minnesota Department of Health will be involved in regulating uranium exploration, mining, and milling.

At present, only privately owned land has been leased for uranium exploration, mining, and related activities. The Minnesota Legislature considered several bills during the 1979 session which would have required stricter regulation of exploration on privately owned land. No consensus was reached, however, and no bill left the House Committee on the Environment and Natural Resources. Currently, the state has no legal means of making reports on exploration activity and lease arrangements mandatory, although several of the involved companies have voluntarily provided some information to the state.

Within current Minnesota laws and regulations, two important responsibilities would be the granting of leases to explore and mine uranium on state lands and the issuance of permits to mine on either state or private lands. State leases would grant permission both for exploration and mining. Any mining would be subject to mined-land reclamation regulations, pollution control regulations, and other restrictions.

Leasing state lands for mineral extraction is a complex process. It begins when the Department of Natural Resources (DNR) receives an indication of interest in leasing state lands for development of a particular mineral resource. Interest in uranium is already evident. The DNR Rules and Regulations now contain a chapter, written and approved in 1956, on "permits and leases on state-owned mineral lands for ores bearing source material" (source material is uranium, thorium, or any other fissionable material). This chapter is being revised because it specifies royalty payments to the state that are higher than uranium mining companies would probably agree to, and it severely restricts the size of blocks which could be offered for sale. The process for changing this chapter has begun; there will be opportunity for public participation and a formal rulemaking hearing.

Before there can be a lease sale, rules must be approved for: rental payments for the state land, the length of any lease, (limited by state law to at most 50 years), the size of individual blocks of land to be offered for lease, and any special performance requirements. The special performance requirements might include such things as: an exploration schedule, a mining schedule should an economic deposit be located, special environmental constraints or performance standards, and any other limits placed on the lease --

for example, in situ mining might be prohibited or there might be a restriction that no mill tailings be placed on state land. Special performance standards may be imposed after a lease sale as well. Before leasing is possible, the Department of Natural Resources must also conduct a review of the potential environmental impacts and determine what areas would be opened for leasing.

The next step would be the issuance of proposed rules to govern lease sales. Public hearings on these proposed rules would be scheduled. The hearings would be held before an independent examiner who would then make recommendations to the Commissioner of the Department of Natural Resources. The State Executive Council (composed of the state constitutional officers) must approve the rules, as must the attorney general. Finally, the rules for leasing would be issued by the DNR and filed with the secretary of state. Only then could the lease sale take place. Given the current situation, the earliest possible lease sale for state-owned uranium lands would be in the spring or summer of 1980.

There would then be a public notice of intent to conduct a lease sale. Sealed bids would be submitted by interested individuals or companies. The royalty payments to the state are the major competitive issue in bidding. On a specified date the Department of Natural Resources would open the bids. There is no obligation to accept any bids. The formal authority to accept and approve leases is reserved to the Minnesota Executive Council.

If leases are granted under current law, they will convey the power to explore and to mine if economic deposits are found, subject to special conditions contained in the lease and other applicable regulations.

The above leasing process applies only to state-owned land; a permit to mine issued by the Department of Natural Resources, would be required before mining could take place on either public or private lands. The conditions, in large part, would be set by rules and regulations authorized by the 1973 Mined Land Reclamation Act (amended in 1976).

Currently, there are no approved rules relating to mine land reclamation in Minnesota. The process that will lead to the first of these rules, which apply only to the mining of iron and taconite, is currently under way.

Although these iron and taconite rules will not be directly applicable to either copper-nickel or uranium mining, the precedents set during this first rulemaking will be important to these other activities.*

In 1977 the legislature passed a law (Mn. Stat. Sect. 116c. 71-74) regulating radioactive waste disposal. That law specifies that before a "radioactive waste management facility" may be constructed or operated, specific legislative approval must be obtained. Whether or not this law applies to exploratory drilling, mining, milling, and tailings disposal depends on interpretations of various provisions in both state law and applicable federal law. Nevertheless, the law may be another vehicle for state regulation, particularly since the 1978 Uranium Mill Tailings Radiation Control Act formally defined mill tailings as radioactive waste.

The Federal Responsibility**

The federal government is also responsible for regulating uranium mining and milling, primarily through the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). However, the Atomic Energy Act provides that states may enter into cooperative agreements with the NRC. Under such an agreement, a state can assume some of the NRC's regulatory authority over nuclear materials. States that assume such authority are known as "Agreement States;" those that do not are known as "Non-Agreement States." Minnesota is a Non-Agreement State. The federal-state relationship in the regulation of uranium mining and milling activities differs significantly between Agreement States and Non-Agreement States.

*The authority of the Commissioner of Natural Resources to prepare mine land reclamation rules is found in Minnesota Statutes 93.44-93.51 (1976). A notice of the hearing on proposed rules relating to mine land reclamation for iron and taconite mining was issued by Commissioner Joseph Alexander on 31 August 1979. The hearing was held at Mesabi Community College, Virginia, Minnesota on October 10, 1979. The proposed rules were published in the Minnesota State Register, 10 September 1979, Vol.4, Number 10, pages 302-317.

**This section draws heavily on the 13 December 1979 testimony of Jay R. Kraemer, Esq., before the Committee on Environmental and Natural Resources of the Minnesota House of Representatives. The complete testimony, and transcripts of the hearing, are available from the Committee.

The Atomic Energy Act designates certain materials as "licensable materials" that are regulated by the NRC. Uranium mill tailings, defined as "byproduct material" under the Atomic Energy Act, and the yellowcake produced by uranium milling, defined as "source material," are licensable materials. Mining wastes and uranium ore are not licensable under the Atomic Energy Act. Because uranium mines and mills are located in close physical proximity, the differences in federal authority over milling and over mining can lead to complex situations.

Generally, Non-Agreement States have more control over unlicensable materials than over licensable materials. One exception is "air pollutants" as defined in 1977 Amendments to the Clean Air Act, which include any "radioactive substance" (source material or byproduct material) that is emitted into the ambient air. Because of this exception, Non-Agreement States retain the right to regulate radioactive air pollutants that might be associated with uranium mining or milling. In Minnesota, the Environmental Protection Agency has delegated to the Division of Air Quality, Minnesota Pollution Control Agency, certain enforcement authority over emission standards for uranium mining and milling. Thus, the 1977 Amendments to the Clean Air Act offer Non-Agreement States the statutory basis on which to plan an active role in the regulation of airborne radioactive hazards.

Since uranium mine wastes are not regulated under the Atomic Energy Act or defined as licensable material, the disposition of mine wastes, into navigable waters or otherwise, is subject to state regulation.

Unlike the Clear Air Act, the Clean Water Act has not been amended to include licensable materials as pollutants subject to regulation. The EPA has promulgated guidelines that limit effluents in discharges from uranium mines and mills. Any discharge permit for a uranium mine or mill, whether issued by the EPA or the state, must contain effluent-limitation conditions at least as stringent as those in the guidelines. A state may, in order to achieve its water quality objectives, require that a permit contain effluent-limitation conditions more stringent than those mandated by the guidelines.

Congress, in its first attempt to address head-on the environmental problems involved in the initial phases of the nuclear fuel cycle, passed

the Uranium Mill Tailings Radiation Control Act of 1978. This act recognizes that mill tailings:

may pose a potential and significant radiation health hazard to the public, and that the protection of the public health, safety, and welfare and the regulation of interstate commerce require that every reasonable effort be made to provide for the stabilization, disposal and control in a safe and environmentally sound manner of such tailings in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards from such tailings.

The reference to "regulation of interstate commerce" is especially important here. It not only lays the Constitutional foundation for enactment of the statute but it also provides the basis for a preemption argument -- that mill tailings and their disposition are so involved in interstate commerce that the states should be prohibited from regulating them except in the context of the federally created regime.

Title II of the 1978 Act, which deals with active uranium mills, clarifies and increases the authority of the Nuclear Regulatory Commission and the Agreement States to regulate the disposition of mill tailings at active milling sites and after termination of uranium mill operations. Mill tailings are specifically made subject to licensing. Section 202 of Title II adds a new provision to the Atomic Energy Act requiring that any uranium mill or mill tailings license issued after November 8, 1981, must contain conditions assuring that, before the license is terminated, the licensee will comply with NRC's decontamination, decommissioning, and reclamation standards for processing and tailings disposal sites and that ownership of the tailings will be transferred without cost to the federal government or to the state in which the milling occurred. The option as to which government, state or federal, will acquire the disposal site and the tailings is the state's, and a state need not be an Agreement State to acquire the site. However, the NRC may determine that the public health, safety, and welfare do not require governmental ownership of the property. In any event, the NRC will issue a license governing the conduct of the custodian of the disposal site. The commission may also determine whether the surface or subsurface of the land transferred to a governmental custodian may be used in a way consistent with public health, safety, welfare and environmental standards.

In addition, Section 203 of Title II permits the NRC to require that a person licensed to possess tailings provide an adequate bond or other financial arrangement to ensure complete mill decommissioning and reclamation before the license is terminated. The NRC is also directed to assure that licenses renewed or issued in the future will minimize the need for post-termination monitoring and maintenance, and that all licenses to possess mill tailings require the licensee to make financial arrangements for whatever post-termination maintenance and monitoring will be necessary before NRC grants license termination. This latter requirement is designed to induce licensees to adopt decommissioning schemes that will be reliable and permanent and to require them to bear financial consequences for the failure to do so.

The Act seems to contemplate the NRC exercising exclusive licensing authority for mill tailings in Non-Agreement States -- subject, of course, to preexisting and retained authority under the Clean Air and Clean Water Acts. The new Act also provides that, prior to November 8, 1981, any state may exercise any authority under state law regarding mill tailings "in the same manner and to the same extent," as permitted before the 1978 Act. So, to the extent that a state could have regulated the radiation hazards of mill tailings prior to the Act, it will retain that authority until November 8, 1981, whether it is an Agreement State or not. In Minnesota, however, no mills could begin operating by late 1981. As to non-radiological hazards, Section 274k of the Atomic Energy Act provides that nothing in Section 274 affects "the authority of any state or local agency to regulate activities for purposes other than protection against radiation hazards." Furthermore, since the NRC does not license uranium mining, nor are mine wastes licensable material, it cannot be argued that the Atomic Energy Act preempts state regulation of radiological hazards from mine tailings.

The Uranium Mill Tailings Radiation Control Act requires the EPA, not later than May 8, 1980, to promulgate standards of general application to deal with the "hazards associated with the processing and with the possession, transfer and disposal" of mill tailings at active uranium ore processing sites and at disposal sites. These standards are to be consistent with those issued under the Solid Waste Disposal Act (as amended by the Resource Conser-

vation and Recovery Act); the EPA may periodically revise these standards, and the NRC or, where appropriate, an authorized Agreement State, must apply these revised standards to licenses within three years of the standards' promulgation. These standards will apply to both radiological and non-radiological hazards associated with uranium milling and mill tailings.

The NRC's proposed regulations for "Criteria Relating to Uranium Mill Tailings" were published in the 24 August 1979 Federal Register. They describe the way the NRC believes mill tailings ought to be dealt with to protect the public health, safety, and welfare and the environment. The proposed regulations were derived from the NRC's Draft Generic Environmental Impact Statement on Uranium Milling (NUREG-0511).

Were there to be uranium mining or milling on Indian lands, the situation would be significantly complicated. Special tribal interests are recognized in both the Mill Tailings Act and Clean Air Act.

In addition to the NRC and the EPA, other federal agencies also have some authority over uranium mining and milling. The health and safety of uranium mines and most uranium mill workers is within the jurisdiction of the Department of Labor's Mine Safety and Health Administration as a result of the Federal Mine Safety and Health Act of 1977. While the 1977 Act does not provide for states taking the primary role in implementing and enforcing mine safety, it does provide that they may enact more stringent health and safety standards for mineral mining (defined to include milling) than those issued by the Department of Labor. The 1977 Act and regulations to enforce it apply to both radiological and non-radiological health and safety hazards.

The Bureau of Land Management, the United States Forest Service, and the United States Geological Survey are all involved in the process of land acquisition for uranium development. Companies must acquire a prospecting permit or a lease to use federal lands from the Bureau of Land Management. The lease is administered for surface-relevant matters by the Forest Service and for mineral-relevant matters by the Geological Survey. A lease contains a mine operating plan which in turn must contain restoration plans. If waste disposal but no mine is contemplated on Forest Service land, the land may be unconditionally exchanged or a special use permit granted.

The Department of Interior's Fish and Wildlife Service may also play a role in the regulatory process. The Endangered Species Act of 1973 mandates that if an area involved in a mining venture is considered a critical habitat, the project would have to be greatly modified or eliminated.

The United States Army Corps of Engineers, under a broad definition of navigable waters adopted by the Corps, can influence uranium development. Activities conducted throughout a uranium facility are subject to the Corps' jurisdiction if they involve dredging or filling in any stream flowing more than five cubic feet per second, any body of water larger than five acres, or in wetlands. Construction permits from the Corps are required for power lines, pipelines, piers, etc. which are on, under, or over waters within its jurisdiction.

MINNESOTA SOURCES OF FURTHER INFORMATION

In addition to the private corporations engaged in exploration for uranium in Minnesota, the following agencies can be consulted for further information:

Minnesota Department of Natural Resources
Division of Minerals
3rd Fl. Centennial Office Building
658 Cedar Street
St. Paul, Minnesota 55155

Minnesota Department of Health
717 Delaware Street S.E.
Minneapolis, Minnesota 55440

Minnesota Environmental Quality Council
State Planning Agency
Room 100 Capitol Square Building
St. Paul, Minnesota 55101

Minnesota State Pollution Control Agency
1935 West County Road B2
Roseville, Minnesota 55113

The Minnesota Coalition on Uranium
618 East 22nd Street
Minneapolis, Minnesota 55404

APPENDIX A: FOR FURTHER READING

GENERAL

The following pages include some of the references used in preparing this booklet, along with others that may be of use to those interested in uranium mining and milling. Several sources of information report ongoing developments in the industry.

- Both the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission have public information departments that publish regular newsletters and provide specific information upon request. Anyone can be placed on the DOE or NRC mailing lists without charge. Send requests to:

U.S. Department of Energy
Office of Public Information
Washington, D.C. 20585

U.S. Nuclear Regulatory Commission
Office of Public Affairs
Washington, D.C. 20555

- Several industry publications report developments in nuclear power, including uranium mining and milling. Among the best of these is:

Nuclear Industry
Atomic Industrial Forum
7101 Wisconsin Avenue
Washington, D.C. 20014

Nuclear Industry should be available in public libraries in areas where nuclear activities are conducted or proposed.

- By far the best and most complete nuclear industry newsletter is Nucleonics Week, published by the McGraw-Hill Company. Virtually all developments of significance to the nuclear industry are reported by Nucleonics Week. Unfortunately, Nucleonics Week is very expensive (a subscription is now \$555 per year), but the newsletter should be available at major public libraries, particularly in areas where nuclear activities are being conducted or proposed.

Nucleonics Week
1221 Avenue of the Americas
New York, N.Y. 10020

- The Rocky Mountain Energy Company recently started a newsletter, Minnesota Report. It is available, without charge, from:

Rocky Mountain Energy Company
4704 Harlan Street
Denver, Colorado 80212

- Several regular sources of information on nuclear activities, including uranium mining, are published by environmental organizations. Three of the best are:

- Amicus, a semimonthly magazine published by the Natural Resources Defense Council (NRDC). It is available to NRDC members, from:

Natural Resources Defense Council
122 East 42nd Street
New York, N.Y. 10017

- Not Man Apart, a monthly newsletter published by Friends of the Earth. A yearly subscription is \$15 or a regular membership, including subscription, is \$25 per year.

Friends of the Earth
124 Spear Street
San Francisco, California 94105

- Critical Mass, a monthly newsletter published by one of Ralph Nader's organizations in Washington. The annual subscription cost for individuals is \$7.50.

Citizens Movement for Safe and Efficient Energy
P.O. Box 1538
Washington, D.C. 20013

- Several publications, while not specializing in uranium issues, regularly include information on nuclear power in general. Two of the best are Science and The Bulletin of the Atomic Scientists. Science is a weekly magazine published by the American Association for the Advancement of Science; its annual subscription price is \$34. The Bulletin of the Atomic Scientists is published monthly; its annual subscription cost is \$19.50. Both of these magazines should be in virtually every public library. Their subscription addresses are:

Science

1515 Massachusetts Avenue Northwest
Washington, D.C. 20005

Bulletin of the Atomic Scientists

1020 East 58th Street
Chicago, Illinois 60637

SPECIFIC SOURCES

What is Uranium?

Encyclopedia Britannica. 1971. Volume 22: 779.

Singleton, Arthur L., Jr. June 1968. Sources of nuclear fuel, Understanding the atom series. Oak Ridge, Tennessee: U.S. Atomic Energy Commission, Division of Technical Information.

Society of Mining Engineers. October 1978. Uranium: a special report. Mining Engineering 30: 1405-1436.

Uranium's Commercial Uses

Encyclopedia Britannica. 1971. Volume 16: 111-112.

Encyclopedia Britannica. 1971. Volume 22: 779.

Singleton, Arthur L., Jr. June 1968. Sources of nuclear fuel, see above, under What is Uranium?

Weaver, Kenneth F. April 1979. The promise and peril of nuclear energy. National Geographic 155: 459-493.

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Lieberman, M.A. 30 April 1976. United States uranium resources: an analysis of historical data. Science 192 (No 4238): 431-436.

Uranium Reserves

McKelvey, V.E. January-February 1972. Mineral resource estimates and public policy. American Scientist 60: 32-40.

Society of Mining Engineers. October 1978. Uranium: a special report.
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Economic Considerations

Faulkner, Rafford. 24 October 1969. "Uranium supply and demand." Paper presented to the Uranium Committee of the American Mining Congress. Washington, D.C.: U.S. Atomic Energy Commission.

Holdren, John P. Uranium availability and the breeder decision. Energy Systems and Policy 1 (No.3): 205-232.

Society of Mining Engineers. October 1978. Uranium: a special report.
See above, under What is Uranium?

Taylor, Vince. 11 February 1977. "How the U.S. government created the uranium crisis: the urgent need to revise U.S. enrichment policies." Los Angeles: Pan Heuristics, a division of Science Applications, Inc.

Taylor, Vince. 25 April 1977. "The myth of uranium scarcity." Los Angeles: Pan Heuristics.

Taylor, Vince. 2 November 1977. "The coming uranium bust." Los Angeles: Pan Heuristics.

Note: The reports by Taylor are available from: Pan Heuristics, Suite 1221, 1801 Avenue of the Stars, Los Angeles, California 90067.

Exploration for Uranium Ores

Sisselman, Robert, ed. November 1978. Uranium fever in the U.S. is spreading as explorationists step up the search. Engineering and Mining Journal 179: 62-69.

Society of Mining Engineers. October 1978. Uranium: a special report.
See above, under What is Uranium?

Uranium Mining

Cox, Jack. September 2-6, 1979. [series of five articles]. Shock waves here from wild U-rush. Radiation spectre haunted early U-miners. Radon guidelines may be weak. Lifeline question of miner: how much radiation? Claims of U-widows hang fire. Denver: The Denver Post.

Hogerton, John F. December 1967. Atomic fuel. Understanding the atom series. Oakridge, Tennessee: U.S. Atomic Energy Commission, Division of Technical Information.

Keeny, Spurgeon M., Jr., chmn. 1979. Nuclear Energy Policy Study Group. Nuclear power issues and choices. See above, under United States and World Sources of Uranium.

Metzger, H. Peter. 1972. The atomic establishment. New York: Simon and Schuster.

Singleton, Arthur L., Jr. June 1968. Sources of nuclear fuel. See above, under What is Uranium?

Society of Mining Engineers. October 1978. Uranium: a special report. See above, under What is Uranium?

Union of Concerned Scientists. 1975. The nuclear fuel cycle: A survey of the public health, environmental, and national security effects of nuclear power. Cambridge, Massachusetts: MIT Press.

U.S. Congress, Joint Committee on Atomic Energy, Subcommittee on Research, Development and Radiation. 1967. Hearings on radiation exposure of uranium miners, parts 1 and 2. 1969. Hearings on radiation standards for uranium mining. [Available from U.S. Government Printing Office, Washington, D.C.]

Uranium Milling and Tailings

American Physical Society. January 1978. Report to the American Physical Society by the study group on nuclear fuel cycles and waste management, Reviews of Modern Physics 50 (No. 1 part II): entire issue.

Berik, Dave. November 1978. Uranium tailings blowing in wind -- new federal legislation is first step in curbing radiation hazard. Critical Mass Journal: 10.

Comey, David. September 1975. The legacy of uranium tailings. The Bulletin of the Atomic Scientists 31 (No.7): 43-45. (Reprinted in Critical Mass Journal October 1975, p.3).

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Deflating the boom in Wyoming uranium. 29 May 1978. Business Week: 26-27.

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- Linker, Helene; Beers, Roger; and Lash, Terry. 1979. Radioactive waste gaps in the regulatory system. Denver Law Journal 56: 1-30.
- Metzger, H. Peter. 31 October 1971. Dear sir: your house is built on radioactive uranium waste. New York Times Magazine: 14-15.
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- Rosenthal, Bruce. May 1976. Uranium milling operations become safety hazard. Critical Mass Journal: 3.
- Sigler, William F. et al. December 1966. The effects of uranium mill wastes on stream biota. Utah Agricultural Experiment Station Bulletin 462. Logan, Utah: Utah State University.
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- Sweet, William. May 1979. Unresolved: the front end of nuclear waste disposal. The Bulletin of the Atomic Scientists 35 (No.5): 44-48.
- Uranium mill tailings: addresses a long-neglected problem. 13 October 1978. Science 202: 191-202.
- U.S. Nuclear Regulatory Commission. November 1978. Final environmental statement related to the Exxon Mineral's Company highland uranium solution [in situ] mining project. Chapter 3. Document number NUREG-0489.
- U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Draft Generic Environmental Impact Statement on Uranium Milling, April 1979 [Volume 1 - Summary and Text, Volume 2 - Appendices] Document number NUREG-0511. Note: When requesting a copy, also request copies of comments received by the NRC on the Draft EIS, and a copy of the Final EIS when it is completed.
- Uranium Exploration in Minnesota
- Ojakangas, Richard W. October 1976. Uranium potential in precambrian rocks in Minnesota. U.S. Energy Research and Development Administration Report GJBX-67 (76).

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Black Hills Alliance. 1979. Miscellaneous brochures. Rapid City, South Dakota.

Cluff Lake Board of Inquiry. E.D. Bayda, chmn. 31 May 1978. "The Cluff Lake Board of Inquiry Final Report." Regina, Saskatchewan, Canada.

Comptroller General of the United States. 5 February 1979. Cleaning up commingled uranium mill tailings: is federal assistance necessary? See above, under Uranium Milling and Tailings.

Ivins, Molly. 27 May 1979. Uranium miners developing lung diseases. Minneapolis Tribune: 10A.

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Minnesota Laws and Regulations

This section was written from information provided by the Minerals Division, Department of Natural Resources; Howard Vogel, Esq., Hamline Law School; and Tom Triplett, Minnesota Project.

The Federal Responsibility

Comptroller General of the United States. 5 February 1979. Cleaning up commingled uranium mill tailings: is federal assistance necessary? See above, under Uranium Milling and Tailings.

Linker, Helene; Beers, Roger; and Lash, Terry. 1979. Radioactive waste gaps in the regulatory system. See above, under Uranium Milling and Tailings.

Society of Mining Engineers. October 1978. Uranium: a special report. See above, under What is Uranium?

Sweet, William. May 1979. Unresolved: the front end of nuclear waste disposal. See above, under Uranium Milling and Tailings.

APPENDIX B: THE URANIUM FUEL CYCLE

Nuclear power reactors are fueled with uranium -- just as the coal fuel cycle begins at the coal mine, the fission fuel cycle begins at the uranium mine. In most respects uranium mining is typical of other hard rock mining, conducted both as underground and as surface operations. The uranium is found in low concentrations in a rock matrix. Uranium concentrations vary from the high-grade deposits currently being exploited to a background level in virtually all rocks composing the earth's crust. The total known resources of uranium is extremely large but the concentrations in which the bulk of this resource exist are low. Hence, although there is no possibility of "running out" of uranium, as lower grades of ore are mined, the quantities of rock moved approach the quantity of coal that would have to be mined to produce the same net amount of energy.

After mining, the uranium ore is milled to recover pure uranium. This milling is not unlike the extractive processes for other metal ores. The rock is crushed to fine particles, and the uranium is removed by a combination of chemical and physical processes. Over 99 percent of the ore is left at the mill site as "tailings" -- fine, sand-like particles.

The extracted uranium, which at this stage is in the form of an oxide called "yellowcake," then passes through some intermediate processing and is sent to the enrichment plant. For technical and economic reasons (based in large part on the existence of large enrichment plants which the United States built for the military weapons program), the most common types of United States power reactors use "enriched" uranium as fuel. Enrichment means that the concentration of the isotope uranium-235 is increased over its concentration in natural uranium, which is over 99 percent uranium-238. The changes resulting from enrichment are as follows:

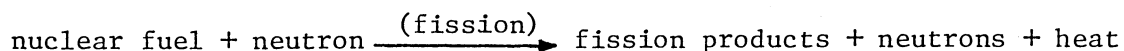
Uranium Isotope	Natural Uranium	Enriched Uranium in Conventional Reactors
U-235	0.7%	3-4%
U-238	99.3%	96-97%

There are three uranium enrichment plants in the United States, located in Ohio, Kentucky, and Tennessee. All were constructed during and after World War II as an integral part of the weapons program.

After enrichment, the uranium is transported to fuel fabrication plants. In these plants the uranium is converted to ceramic pellets of uranium dioxide (UO_2) -- the form in which the uranium is used as part of the reactor fuel. These pellets are inserted into long, thin-walled tubes, called cladding, each about one-half inch in diameter and some twelve feet long. The filled tubes are called fuel rods or fuel pins. These fuel rods are assembled into bundles, the geometry of which is carefully controlled, and held in place by various structural members. These mechanical assemblies of fuel rods and structural members are called fuel elements.

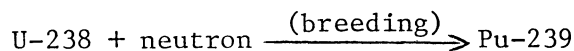
The fuel elements are then transported to the site of the nuclear power plant, the reactor. Although reactors are complex machines, for purposes of understanding the nuclear fuel cycle it is sufficient to consider only two nuclear reactions that take place within them. These reactions are (1) the splitting, or fission, of the nuclear fuel in which energy and neutrons are produced and (2) the "breeding" of additional nuclear fuel from "fertile" material and neutrons. All nuclear reactors, current or proposed, burn one of three fuels: uranium-233, uranium-235, or plutonium-239. As noted, the fuel used in today's reactors is uranium-235, the only one of the three potential fuels which occurs in any quantity in the earth's crust. Virtually all U-233 and Pu-239 is man-made. The process of making these two fuels is called "breeding."

The reaction which produces the heat, which boils the water, which makes the steam, which turns the turbine, which produces the electricity, which runs Jack's toothbrush is the splitting of an atom of nuclear fuel:

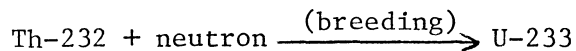


The fission products are two elements lighter than uranium and are highly radioactive. They constitute most of the "high-level" radioactive waste associated with nuclear fission. The quantities and composition of the fission products for each fuel are quantitatively similar.

Much of nuclear reactor engineering is concerned with the conservation of the neutrons which are produced by fission. These neutrons end up in one of three places. At least one of the two or three neutrons produced in each fission must be used to fission another atom of nuclear fuel and maintain the chain of fission reactions. Some of the neutrons are wasted by being absorbed by structural materials in the reactor, by fission products, by the reactor coolant, or in other ways are lost. Much effort goes into minimizing the number of neutrons wasted in this way, for there is another reaction that is encouraged, "breeding" of more nuclear fuel. As indicated above, the largest component of the uranium fuel is not the fissionable isotope, U-235, but is nonfissionable U-238. U-238 is, however, a "fertile" material and undergoes a reaction with neutrons to "breed" the fuel plutonium-239:



Although most of the current generation of nuclear power plants use the uranium-plutonium cycle, it is also possible to breed fuel from another common element, thorium. Thorium-232, like uranium-238, is a naturally occurring isotope. Thorium-232 is not a fuel but it is a fertile isotope from which the fuel uranium-233 can be bred. The reaction is similar to that which produces plutonium-239:



All of this description is equally applicable to the current generation of reactors and to the more advanced types of reactors that are being proposed. Today's reactors are called "burners" because they burn more fissionable material than they produce. Plutonium is made in today's "burners," but less than one atom of plutonium is produced for each atom of uranium-235 that is split. A key difference between today's burners and the proposed "breeder reactors" is that a breeder reactor would produce more than one atom of the fuel plutonium-239 for each atom of fuel that undergoes fission.

The fuel elements are placed in the reactor and remain there for a variable length of time, typically three years, during which time the fission and breeding reactions take place in the fuel. During this period the concentration of U-235 fuel is being reduced and the concentrations of fission

products and Pu-239 are building up in the fuel. After being removed from the reactor, the used fuel elements are known as "spent fuel." Unlike the new fuel, spent fuel is highly radioactive, thermally hot because of the decay of the radioactive fission products, and extremely dangerous to handle. The spent fuel is stored at the reactor site for several months to permit it to cool.

The fuel cycle described thus far already exists in the United States today, at least insofar as burner reactors are concerned. There are enrichment facilities, several uranium fuel fabricating plants and about 100 nuclear power reactors either in operation or under construction. However, the remaining steps in the fuel cycle -- the so-called "back end" of the cycle -- remain to be commercially implemented, and breeder reactors have not yet been introduced beyond the experimental stage.

Nuclear industry plans call for the eventual shipment of spent fuel from reactor or other storage sites to chemical reprocessing plants. At the reprocessing plant the spent fuel would be mechanically chopped up, dissolved in acid, and a chemical separation system used to isolate three of the component parts: (1) the remaining uranium, (2) the fission products, and (3) the plutonium. The principal purpose of commercial reprocessing would be to recover the plutonium for future use as reactor fuel.

The recovered uranium would be recycled back into the nuclear fuel cycle by returning it to the enrichment plant. It has also been proposed that the plutonium be used as fuel for other nuclear power reactors. Were that application found acceptable, the plutonium would be shipped directly from the chemical reprocessing plant to a fuel fabrication plant.

The fission products, and other radioactive wastes produced by the nuclear reactor, constitute the high-level radioactive wastes. The "other radioactive wastes" include "activation products" -- those materials in and near the reactor core which are made radioactive incidental to being in the reactor -- and "transuranic elements." Although they constitute a small fraction of the radioactive wastes, the presence of the transuranic elements complicates the management of the wastes. The two principal reactions which take place in a reactor were mentioned above. The transuranic elements -- those with atomic number greater than that of uranium -- are produced by

several reactions that begin with the capture of a neutron by uranium but which do not lead to fission. The breeding reaction which produces plutonium from uranium is an example. Other transuranic elements, such as neptunium, americium, and curium, are also produced and are retained in the radioactive waste, as is a small portion of the plutonium-239, after reprocessing. They are highly radioactive. Many of them have exceedingly long half-lives, measured in hundreds of years to tens of thousands of years rather than the half-lives of about 30 years or less associated with the most troublesome of the radioactive fission products.

Because of their deadly radiation, these reactor wastes have to be isolated from the biosphere for hundreds of thousands of years. Were the wastes composed only of fission products, one could credibly talk about waste storage for only about 1,000 years, a staggering task in itself. But because of the presence of the transuranic elements in the waste, the storage time is extended to hundreds of thousands of years. The radioactive wastes must be completely isolated from the biosphere essentially forever.

Appendix B is reproduced here with minor revisions from:

National Council of Churches of Christ in the U.S.A., Committee of Inquiry:
The Plutonium Economy. The Plutonium Economy: A Statement of Concern.
September 1975. New York: National Council of Churches, 475 Riverside Drive, New York, N.Y. 10027.

Two other sources of information on the nuclear fuel cycle are:

Keeny, Spurgeon, M., Jr., 1979. Nuclear Energy Policy Study Group.
Nuclear power issues and choices, Sponsored by the Ford Foundation.
Cambridge, Massachusetts: Ballinger Publishing Company.

Union of Concerned Scientists. 1975. The nuclear fuel cycle: A survey of the public health, environmental, and national security effects of nuclear power, Cambridge, Massachusetts: MIT Press.

APPENDIX C: RADIOACTIVE DECAY PRODUCTS FROM URANIUM

Radioactive materials make the hazards associated with mining and milling of uranium different from those of most other mining. Uranium is radioactive, and it gives rise to several other radioactive isotopes when it undergoes radioactive decay.

When an isotope undergoes radioactive decay its nucleus gives off a particle, either an alpha particle or a beta particle. An alpha particle is composed of two neutrons and two protons. It has a positive charge. It is the same as a nucleus of a helium atom. A beta particle is a high-speed electron. It has a negative charge and is several thousand times lighter than an alpha particle. In some cases radioactive decay is also accompanied by the emission of a gamma ray. A gamma ray is a very high-energy x-ray.

These different particles have different biological effects. An alpha particle can be stopped by a sheet of paper or by about two inches of air. However, during its passage through materials, whether paper or biological tissue, it releases a large amount of energy in a short distance. Beta particles and gamma rays are called "penetrating radiation" because they, unlike the alpha particle, can penetrate large distances of material before losing their energy. The total amount of energy they transfer to biological tissue may be the same as an alpha particle, but it is transferred over a greater distance.

The intensity of radioactivity, or the "specific activity" of a sample of radioactive material, is determined by its "half-life." The half-life is a measure of how probable it is that any given atom will undergo radioactive decay in any given interval of time. For example, radium-226 has a half-life of 1,660 years. That means that in any given sample of radium, half of the atoms will break down in the course of about 1,660 years. Of the remaining atoms, half will decay during the next 1,660 years, and so on.

Uranium mining requires that the ore contain relatively large amounts of uranium. Uranium has a half-life of about four and a half billion years. That means that uranium undergoes radioactive decay rather slowly: a large fraction of the uranium present when the earth was formed still survives.

When uranium decays, the first daughter product is thorium-234. Thorium-234 in turn undergoes radioactive decay to protactinium-234, which decays to uranium-234, which decays to thorium-230, which decays to radium-226, and so forth, through several decays until the "stable" isotope lead-206 is reached. Lead-206 is not radioactive. It does not undergo radioactive decay.

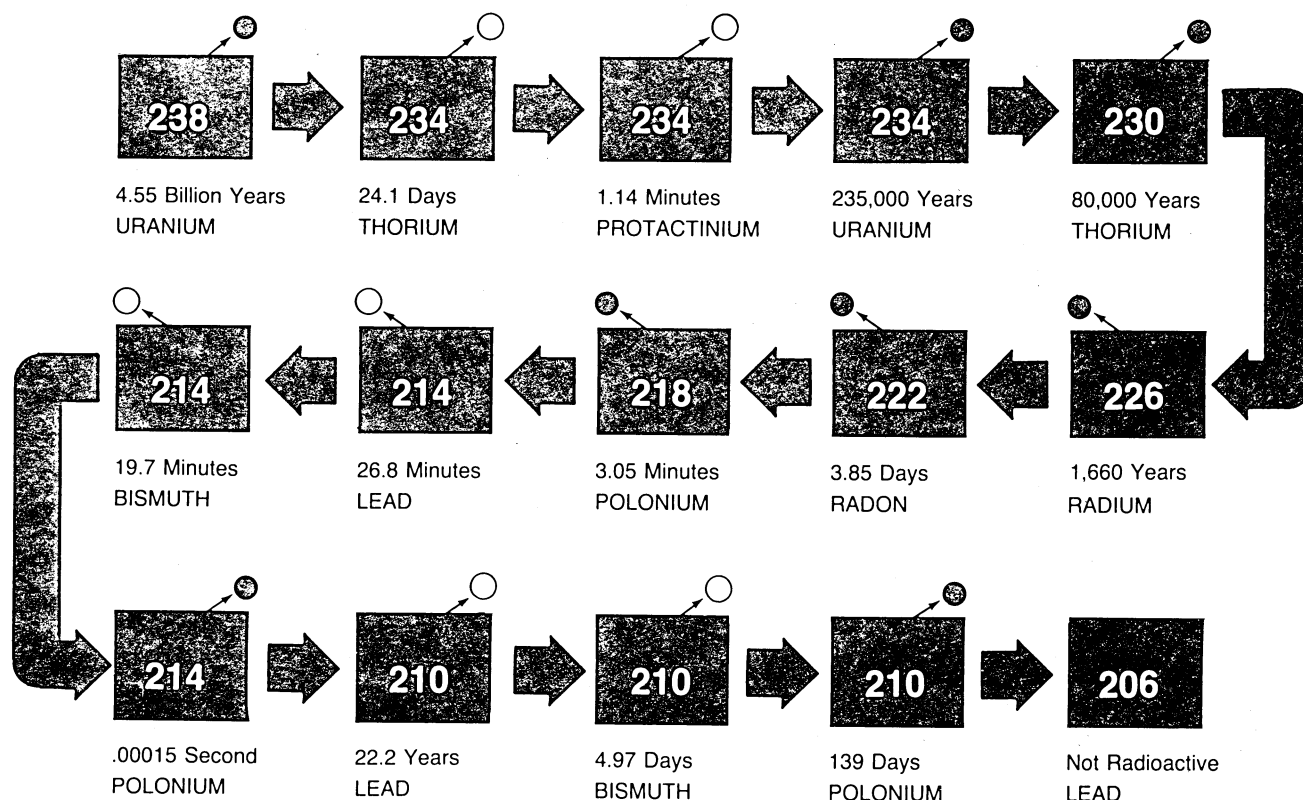
In the mining and milling of uranium ore, it is the radioactivity of uranium and the various daughter products formed between uranium-238 and lead-206 that poses a health hazard.

The radiation exposure from uranium mining arises in part from the gamma radiation given off by the uranium ore, but primarily from radon. Radon results from the decay of radium. As radon is a noble gas it diffuses freely through rock. It is thus present in the atmosphere of all uranium mines and also in the ventilation air from uranium mines. Radon has a half-life of only 3.8 days. It decays into several daughter products, each of which also has a short half-life. Some of the daughter products are alpha emitters, for example polonium-218. Others are beta emitters, for example lead 214. The daughter products attach themselves to dust particles in the air and, along with radon, are inhaled into the lung. A large fraction of these radioactive small particulates are deposited in the deep respiratory tissue where they can remain for long periods of time. It is the radiation exposure from radon and its daughter products which causes lung cancer and other respiratory diseases in uranium miners.

Almost all of the radioactivity associated with the uranium ore ends up in the mill tailings, because only the uranium is removed in milling. Virtually all of the thorium, radium, and other daughter products of uranium decay remain in the tailings.

Although each of the radioactive daughter products of uranium contribute to the tailings hazards, those of primary concern are radium and radon. Radon gas is given off by tailings piles just as it is in the uranium mine, mixing with the air and resulting in radiation exposures through lungs and other tissues. In addition, radium can be leached or eroded from tailings piles and find its way into surface and underground water. Radium is handled by the human body much as calcium is. Therefore, much of the ingested radium is deposited in bone and other hard tissue. Just as the radon taken into the lung gives rise to lung cancers, the radium gives rise primarily to bone

How Uranium Breaks Down Into Radium and Then Into Lead



Figures in the boxes indicate atomic weights of each element.
Times below each box indicate the half-life period of each element.

- indicates an alpha particle given off
- indicates an electron given off

cancer and leukemia. A study of the development of cancer in persons who painted radium on watch dials is a classic in the public health literature.

The radioactive decay products from tailings piles and uranium mining waste can find their way into surface waters, into stream sediments, and through other routes leading to human exposures to radiation.

Ironically, it is these same mechanisms that form the basis for the standard exploration methods for uranium ore. By measuring surface radioactivity, radioactivity in stream sediments, and radioactivity in well water, deposits of uranium ores can be located. The radioactive waste products in mine and mill tailings will migrate in a similar way.

For Further Reading

Samual Glasstone, Sourcebook on atomic energy. 3rd edition. 1967.
Cincinnati: Van Nostrand.

APPENDIX D: RADIOACTIVITY AND ITS EFFECTS ON HUMANS

From 1960 to the present, an overwhelming amount of data have been accumulated that show there is no safe level of exposure and there is no dose of radiation so low that the risk of a malignancy is zero. Therefore, the question is not: Is there a risk from low level exposure? Or, what is a safe level of exposure? The question is: How great is this risk? Or, how great may be a particular radiation risk be before it exceeds the expected benefits, such as those from medical radiography or nuclear power?

Karl Z. Morgan. The Bulletin of the Atomic Scientists. September 1978.

If a number of recent reports are right, the harmful effects of low doses of radiation may be substantially -- perhaps 10 times -- greater than previously estimated. These reports, which fly in the face of the conventional view of the dangers of low-level radiation, have added new fuel to the ongoing controversy over the adequacy of the standards set by the U.S. government to regulate medical, occupational, and environmental exposures to radiation.

Jean L. Marx. Science. April 13, 1979.

These two quotations, taken from the papers cited at the end of this appendix, illustrate the difficulty in dealing with the question of the health effects of low-level exposures to radiation. Exposure to relatively high levels of radiation is known to cause cancers and genetic mutations. The kind of cancer depends on the nature of the radiation and the parts of the body that receive the exposure. The number of genetic effects, or mutations, is determined by the amount of radiation exposure to the gonads -- the testes and the ovaries.

In assessing the impact of uranium exploration, mining, and milling, it is not appropriate to consider the hazards of exposure to high levels of ionizing radiation. These high exposures can result from the use or testing of nuclear weapons, from major accidents in nuclear power plants, or from other accidents, but they cannot occur in uranium mining or milling operations. Uranium exploration, mining, and milling can result in chronic low-level radiation exposures to persons who live or work in the vicinity

of uranium mining operations. The uncertain effects associated with these low-level exposures are the subject of considerable scientific and political controversy.

The political controversy has been sharply focused by, for example, the Nuclear Regulatory Commission in its Draft Generic Impact Statement on uranium mining (see citation under Uranium Milling and Tailings in Appendix A):

... there is the question of deciding how much averting a health effect ("life" or "life shortening" in the case of a premature cancer death) is worth in monetary terms; that is, of deciding what the cost-benefit decision criteria should be. It would be difficult to decide the worth of health effects today, and more difficult to decide the worth of future effect (that is 1,000, 100,000 years and beyond). Does a premature loss of life 100,000 years into the future have the same value as a life today?

In addition to this political decision, there is considerable uncertainty about the extent of the health effects that result from low-level exposure to ionizing radiation.

Rather than attempt to summarize this very difficult topic, the reader is referred to two recent scientific discussions of the low-level radiation effect controversy written from different viewpoints. The first, a summary of current research, is from Science, the publication of the American Association for the Advancement of Science. The second, a summary by Karl Z. Morgan, who is among the most respected of the world's health physicists, is from The Bulletin of the Atomic Scientists. Both articles include references to other reports in which the controversy is reported in more detail.

FOR MORE INFORMATION:

Marx, Jean L. 13 April 1979. Low-level radiation: Just how bad is it? Science 204: 160-64.

Morgan, Karl Z. September 1978. Cancer and low-level ionizing radiation. The Bulletin of the Atomic Scientists 34: 30-41.

APPENDIX E: MINNESOTA PERMIT AUTHORITIES

The following list of state governmental units includes all those which might be approached for permits, approval, or licenses to commence mining. Some of those listed may not be affected if the mine site does not interfere with their jurisdiction.

Department of Natural Resources, Division of Waters

- Permits for surface water appropriations, both for plant use and dam construction.
- Permits for ground water appropriations, mine dewatering, plant use, and potable water supply.
- Permits for working in beds of public waters (altering the courses' current or cross section), in the following circumstances: for implementation of intake and discharge structures, including dredging; stream diversion; dam construction; dam abandonment; or draining, diverting, and controlling waters in order to mine.
- Permits for flooding state lands.
- Permits for utilities crossing public lands and waters.
- DNR has power to review county regulations on shoreland development.
- Report to DNR drill data on ground water supply wells.
- DNR has authority to examine and require repair of dams.

Department of Natural Resources, Division of Minerals

- Approval of Executive Council for draining lakes in mining operations.
- Prospecting permits and leases on state lands (Minnesota Executive Council).
- Permit to mine, requiring mineland reclamation.
- Permit to deposit tailings in public lake (defined as any body of water at least 80 acres in area).
- Authorization to reduce or smelt ore.

Pollution Control Agency, Air Quality Division

- Air quality permits (installation and operating permits for point sources of air pollution).
- Joint authority for state disposal system permit for tailings basin.
- Review authority for all mine areas to assess total air quality impacts.

Pollution Control Agency, Noise Division

- Administers rules and regulations on non-impulsive noise.

Pollution Control Agency, Solid Waste Division

- Permit for disposal of residual materials such as scrubber sludge (does not include stockpiles or tailings).

Pollution Control Agency, Water Quality Division

- Permit for national pollutant discharge elimination system (all point source discharges).
- Joint authority for state disposal system permit for construction and operation of closed waste treatment or disposal facilities; also tailings basins, settling basins, sewage treatment.

Department of Health

- Written approval for sewage disposal plans, plumbing plans, and potable water supply plans (including water well construction).
- Inspection and consultation on occupational disease requirements.

Department of Labor and Industry, and Occupational Safety and Health Administration

- Written approval of any elevators.
- Safety and health inspection.

Energy Agency

- New Operations require certificate of need if they include any of the following: 1,000,000-gallon oil storage; 7,500 tons coal storage; 125,000 tons coal (annual use).
- Under the agency's definition of nuclear fuel processing facility, a certificate of need may be required for the mining or milling operations.

Department of Transportation

- Roads on mineral land may be relocated by the operator subject to approval by the road authority.
- Permit to use or cross right-of-way permanently for placement of utilities or haul roads.
- Permit to use right-of-way temporarily.
- Driveway permit from district office to have a road adjoin a state highway.
- Overwidth/overweight load permit.

Department of Transportation, Division of Aeronautics,
and Federal Aviation Administration

- Provide notice of proposed construction or alteration for chimney elevations over 200 feet or within 20,000 feet of a public airport -- no permit required.

Department of Transportation, Division of Railroads, Ports, and Pipelines

- Approval to abandon railroads and ports.

Environmental Quality Board

- New mineral processing or refining facilities must prepare an environmental assessment worksheet prior to the granting of any governmental permit.
- Based on the worksheet, an environmental impact statement may or may not be required.
- Permits required if mining operations in state designated critical areas.
- New power plants and transmission lines subject to review.

State Planning Agency

- Park and open space areas receiving LAWCON funds would require review by Planning Agency and approval by federal government prior to any use by mining interests.

Department of Public Safety, State Fire Marshall

- Must meet minimum requirements of state fire code and get approval for storage of combustibles and flammables.

Bureau of Criminal Apprehension

- Explosive dealer's license.
- Explosive storage and use regulations.

County

- Building permit
- Shoreland development permit.
- Land use permit (rezoning, special, or conditional use).
- Approval of county mine inspector.
- Explosive user's permit from sheriff (if not in police jurisdiction).

Municipality

- Building permit.
- Zoning compliance.
- Explosive user's permit from police chief.

Township

- Burning permit.
- Zoning compliance.

The agencies and governmental units listed above would be involved with essentially all mining ventures, including uranium mining.

Uranium in Minnesota. Revised ed.

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